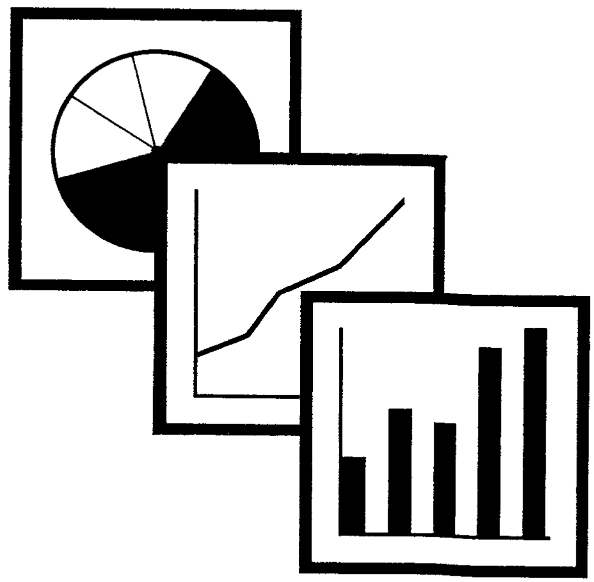
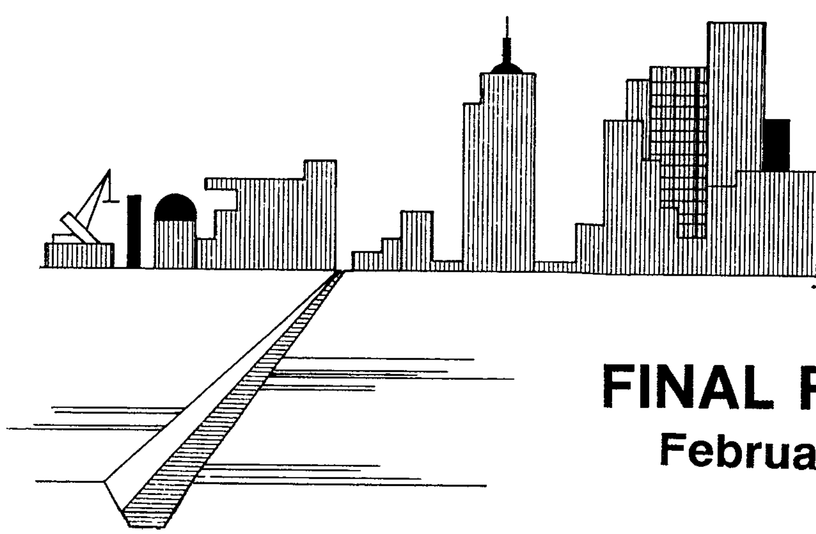
ESTIMATING ECONOMIC IMPACTS OF SALINITY OF THE COLORADO RIVER





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16. ABSTRACT

This research report discusses findings from a study designed to develop a method of forecasting economic impacts of salinity of the Colorado River upon various users of Colorado River water in the southwestern United States. One objective was to update, revise, clarify, and refine the estimates of economic damages from salinity in the Colorado River that had been described in earlier studies. Another objective was to provide a better means of estimating present and future salinity damages, basically through the development of a comprehensive and user-friendly personal computer program. A final objective addressed unresolved questions and issues about Colorado River salinity, including areas of damage not previously included in estimates.

By using one or more selected baseline salinity levels, a potential problem is avoided: that of measuring damages against an idealized water supply that rarely exists in nature and could never be achieved technologically or economically for most water supplies. Measuring against such a water supply would exaggerate the true damage figure.

The total damages from Colorado River salinity range from $310.8 million to $831.1 million annually based on the 1976-85 average level of river salinity and two selected baseline values.

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CONTENTS

Note: CRSDE Program and standard CRSDE input data discs are included in the Instructions for Using the Colorado River Salinity Damage Estimation Program.

FIGURES

TABLES

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PREFACE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the U.S. Department of the Interior, Bureau of Reclamation, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, cost data, computer program, or analytical process disclosed, or represents that its use would not infringe privately-owned rights.

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J. Andrew Schlange, Manager of the Santa Ana Watershed Project Authority, spent nearly two days opening the workings, history, and plans of his Agency to this study.

Members of the three California Regional Water Quality Control Boards covered by this study devoted time and thought to our queries on several occasions. In particular, we thank Jim Bennett from Riverside, Ladin Delaney from San Diego, and Dennis Dasker from Los Angeles.

Tim Henley and Steve Olson of Arizona's Department of Water Resources developed contacts and set meetings for us in Phoenix and Tucson.

George Blake of the Colorado River Commission of Nevada provided a comprehensive list of contacts and suggestions for interviews in the Las Vegas Valley.

Staff of the Metropolitan Water District of Southern California, listed in Appendix B, contributed many hours to seek answers to our questions.

Staff and officials of the City of San Diego and the San Diego Water Authority spent extra time and effort on this project.

The Colorado River Water Quality Office, our sponsor, was consistently helpful and responsive to requests for information.

Finally, the authors wish to thank everyone not mentioned by name for their time, effort, and courtesy. As usual, those with information are unfailingly willing to share it. For this we are especially grateful.

ABBREVIATIONS AND DEFINITIONS

ABS – acrylic butylene styrene (plastic used for wastewater pipe)
af – acre-foot
afy – acre-feet per year
ASTM – American Society for Testing and Materials
AWWA – American Water Works Association

BLM – United States Department of the Interior, Bureau of Land Management
$CaCO_3$ – calcium carbonate (used as an index of water hardness)
CAP – Central Arizona Project
CO_2 – carbon dioxide
CRB – Colorado River Basin

CRSDE – Colorado River Salinity Damage Estimation [the computer program and input data developed in this study]
CRSS – Colorado River Simulation System
CPVC – chlorinated polyvinyl chloride (plastic used for water pipe)
cwt – hundredweight (= 100 pounds)
DO – dissolved oxygen

dS/m – deciSiemens per meter, a measure of electrical conductivity equal to one millimho per centimeter (mmho/cm)
e – the natural exponential, or base of natural logarithms, approximately 2.71828
EPA – U.S. Environmental Protection Agency
GNP Implicit Price Deflator – A quarterly price index published by the U.S. Department of Commerce
hardness – water hardness is described in terms of temporary hardness, permanent hardness, and total hardness.

maf – million acre-feet
M&I – municipal and industrial
mgd – million gallons per day
mg/L – milligrams per liter
mmho – millimho

mmho/cm – millimho per centimeter
µmho – micromho (0.001 millimho)
MWD – Metropolitan Water District of Southern California
O&M – operation and maintenance
OLAC – Orange and Los Angeles Counties [joint sponsors of a 1981 water reuse study]

OWRT – U.S. Department of the Interior, Office of Water Research and Technology (since 1985, a part of the U.S. Geological Survey)
pH – the negative logarithm of the effective hydrogen ion concentration; used as a scale to express degree of acidity/alkalinity
PC – personal computer
Permanent hardness – refers to the presence of chlorides or sulfates of calcium and magnesium which cannot be removed by boiling
P.L. – Public Law

ppm	– parts per million
psig	– pounds per square inch gauge
PVC	– polyvinyl chloride (plastic used for wastewater pipe)
RO	– reverse osmosis
SAE	– Society of Automotive Engineers
SAWPA	– Santa Ana Watershed Project Authority
SIC	– Standard Industrial Classification
t	– TDS (in Tihansky's formulas)
TCE	– Trichlorethylene
TDS	– total dissolved solids

Temporary hardness – refers to the presence of bicarbonate compounds of calcium and/or magnesium. If the water is boiled or acidified, the bicarbonates are decomposed and some hardness compounds precipitate as calcium carbonate or as magnesium hydroxide.

TH	– Total hardness is the combination of temporary and permanent hardness.
USBR	– United States Department of the Interior, Bureau of Reclamation

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SUMMARY OF MAJOR FINDINGS

This research report discusses findings from a study designed to develop a method of forecasting economic impacts of salinity of the Colorado River upon various users of Colorado River water in the southwestern United States.

One objective of this research was to update, revise, clarify, and refine the estimates of economic damages from salinity in the Colorado River that had been described in earlier studies, particularly that of Jay C. Andersen and Alan P. Kleinman, et al., in *Salinity Management Options for the Colorado River* [1978] and the subsequent summary by Kleinman and Bruce F. Brown, *Colorado River Salinity: Economic Impacts on Agricultural, Municipal and Industrial Users* [1980]. Another objective was to provide a better means of estimating present and future salinity damages, basically through the development of a comprehensive and user-friendly personal computer program. A final objective addressed unresolved questions and issues about Colorado River salinity, including areas of damage not previously included in estimates.

These major objectives were undertaken in research severely limited, not only in time and funding, but also constrained in scope. The Bureau of Reclamation placed the following constraints on the research: (1) only direct damages were to be considered; (2) only damages within U.S. borders were to be considered; (3) damages could not be separated as to ion composition or other constituents of the water; and (4) a basin-wide perspective was to be maintained.

Primarily because of the limitations of time (eleven months) and funding (0.71 person-years of professional effort), the major emphasis of the study was devoted to three tasks: (1) rethinking the concepts of salinity damage to determine if other types of damage had heretofore been overlooked or neglected; (2) exploring new as well as existing methods of calculating future salinity damages to assure that all significant factors that affect damage estimates are considered; and (3) designing a comprehensive computer model and calculation program to allow many persons to independently conduct forecasts according to their choice of assumptions for the value of computational factors. The concepts, methods of calculation, and particularly, the computer program are considered to be of much higher quality than the data which are available to use in the model, despite a new effort to find better data sources. The data deficiencies could not be remedied with the resources available to the study team.

Because it is good economic research when dealing with such a complex topic that is subject to the above mentioned limitations and data constraints, the authors have adhered to the dictum of Economics Professor Emeritus Reuben Zubrow, who maintains that it is better to be loosely correct than to be precisely incorrect. Nowhere is this dictum more true than in attempting to define the economic damages caused by salinity in the water of the Colorado River.

Water quality damage itself is a complex subject that can involve the composition, temperature, and velocity of the water, the type of treatment the water receives; the way in which water is used; and the very definition of what is a damage. For all these reasons, damage can rarely be fully and specifically attributed to salinity alone. However, salinity is one water quality constituent that is generally known and understood (where some others are not), and the temptation to attribute damage can be great. In the areas covered by this study, some types of damage can be more clearly attributed to salinity than others, but few damages can be fully accounted for without more specific and comprehensive study engaging a broader range of disciplines – science, engineering, chemistry, biology, and social science, as well as economics. This report, therefore, presents a "loosely correct" picture of economic damages that can, all or in large part, be attributed to salinity in the Colorado River.

Salinity Damage Levels

The salinity levels of the Colorado River, in this study, are taken from the Colorado River Simulation System (CRSS) developed by the Bureau of Reclamation. The flow-weighted average annual estimates cover the period from 1985 to 2010. Under the 1987 version of the CRSS simulation used in this study, salinity below Hoover Dam is projected to go from its 1986 value of about 542 mg/L TDS to about 790 mg/L TDS by 2010. Below Parker Dam salinity is projected to increase from about 542 mg/L TDS in 1986 to about 822 mg/L TDS by 2010. At Imperial Dam, salinity will rise from about 579 mg/L TDS in 1986 to about 958 mg/L TDS by 2010. These are the present and future salinity level estimates used in this report. Another group of salinity values also are used for comparison. These are the ten-year average (1976-1985) levels of salinity at the reservoirs: 652 mg/L TDS at Hoover; 678 mg/L TDS at Parker; and 767 mg/L TDS at Imperial. These levels are considered more representative of past and probable future conditions in the river.

Salinity levels for major metropolitan areas in the Lower Colorado River Basin are much more difficult to estimate. Almost all metropolitan water supplies of Colorado River water are blended with local ground or surface water, or with imported surface water. Further, salinity or TDS is not a very frequently measured water quality parameter of municipal supply. Using the best available data, the authors can provide estimates of current water supply average TDS for broad metropolitan areas. These averages range from 405 mg/L to 579 mg/L TDS for a 1986 current value; and from 450 mg/L to 767 mg/L TDS for the ten-year average value.

There are various levels of concentration at, or above, which salinity in water can cause some type of economic damage. In agriculture that level is where a decline in crop yield begins to occur. For households the damage level is dependent on the type of household item subject to corrosion or scale from contact with saline water (water pipes, hot water heater, etc.) and sometimes on the type of treatment the homeowner gives the water. For water and wastewater utilities the level is where salinity begins to reduce the useful life of facilities and equipment. For industry there are known TDS limits for particular processes, above which levels water treatment is necessary, and industry must pay the costs of treatment. In addition, other economic costs to industry can result, not from actual corrosion or scale, but from regulation of permissible TDS levels in discharge water that can affect the useful life of the water, i.e., number of times the water is used. In such cases, industry must pay additional costs, either for greater quantities of water or for water treatment.

Salinity Effects vs. Salinity Damages

Earlier attempts to measure the effects of salinity have treated such effects as absolute. That is, the physical effects of salinity levels in reducing crop yields, in corroding and thus reducing the useful life of water-using household devices, etc., have been measured against an "ideal" salinity level at which no physical effect is apparent. Then these physical effects are described in economic terms, such as the value of reduced crop production and the monetary costs of more frequent replacement of washing machines, household piping, etc. Such an approach can be misleading.

This measurement of physical and economic effects of salinity in water supply against an ideal water supply appears to have been taken with little justification. It may reflect merely an assumption that saline water has deleterious effects which logically should be measured against a standard of pristine water whose salinity level is below the threshold that causes measurable effects. However, such pristine water is not always found in nature and certainly is rarely found in waters that have been subjected to the impacts of human activity.

This leads to a fundamental question underlying this study, a question whose answer has a major influence on the study findings, yet one that cannot be answered solely through engineering or economic analysis. That is, which physical and economic effects of saline water should be termed "damages"?

The question of effect versus damage relates not only to water source, but to the cause of the salinity, the use to which the water is put, and whether the use is appropriate or well-managed. In direct answer to the question, "Should every negative salinity effect be considered a damage?," it is the judgment of the authors that each negative impact should not be, and could not be, considered a damage. Instead, the impacts of current salinity should be compared with those of a baseline salinity level that can be justified as a basis for comparison.

By using one or more selected baseline salinity levels a potential problem is avoided: that of measuring damages against an idealized water supply that rarely exists in nature and could never be achieved technologically or economically for most water supplies. Measuring against such a water supply would exaggerate the true damage figure. Instead, it is proposed to measure the physical and economic effects of two or more water supplies – one with current salinity levels and another one or two with selected baseline salinity levels – and subtract the latter from the former. The difference in the economic effects, or costs, between two or more salinity levels has been selected in this study as the appropriate measure of salinity "damages."

The selection of appropriate baselines has been a matter of intense discussion among the authors, with the Bureau of Reclamation, and with the Work Group of the Colorado River Basin Salinity Control Forum. Agreement was reached regarding the selection of two baselines which, in conjunction with a current salinity level would bound the range of salinity damages. They are: 334 mg/L TDS and 500 mg/L TDS.

The first, 334 mg/L TDS, was determined by EPA to be the River's natural TDS level caused by natural point and diffuse sources at Hoover Dam based on the 1942-1961 hydrologic record. The second is the EPA Secondary Drinking Water Standard of 500 mg/L TDS, the standard widely used by various health agencies as well as by EPA.

Damages to Agriculture

The authors recognize that salinity damage to agriculture can involve more than a reduction in crop yield or in acreage planted. However, such other damage categories as labor costs, resulting from a need for more frequent irrigations or from the need to clean drain tiles, and capital costs for automated irrigation equipment or for installation of drains are fairly site-specific. Research on these questions revealed that it is not possible to quantify, let alone project, the amount of the costs in a basinwide perspective, or to separate that portion of costs attributable to salinity damage from costs incurred by good farming practice. Review of existing studies and interviews with knowledgeable persons in Lower Basin agricultural areas revealed that the attribution of such costs to salinity alone is unrealistic.

In keeping with the guiding dictum, the authors have chosen to focus on crop yield, crop acreage, and cropping patterns because these are consistently and regularly reported throughout the basin and are most clearly related to salinity. The nine crops selected for the computer program represent an average 80 percent of crop value for the affected areas. Eight of these commonly grown crops have salinity damage thresholds that are below the CRSS projected level of TDS for the Colorado River at Parker and Imperial Dams. They are Lettuce (555 mg/L TDS); Carrots (427 mg/L TDS); Oranges/Tangerines (725 mg/L TDS); Grapefruit (768 mg/L TDS); Onions (512 mg/L TDS); Lemons/Limes (768 mg/L TDS); Table Grapes (640 mg/L TDS); and Avocados (427 mg/L TDS). Alfalfa hay at (853 mg/L TDS) is above the level at Parker, but below the projected level at Imperial Dam.

The annual dollar losses to these nine crops that may be fairly attributed to the salinity of Colorado River irrigation water ranged from \$112.8 million to \$122.5 million (based on the ten-year average salinity level) subject to variations due to non-water factors such as weather, pests, and crop market prices.

Damages to Households

As noted, damages to households depend on a number of factors that are related to salinity or that can be aggravated by salinity. First among these is water hardness which, for the Colorado River, is directly proportional to salinity, constituting 49 to 53 percent of the TDS value, in parts per million. It is water hardness that can cause scale, noticeable effects on cleaning, and unpleasant taste. Water hardness is most likely to be an incentive to water softening, which in turn can affect the corrosivity of the water. The exchange of sodium for calcium ions during softening creates an even more unpleasant taste, stimulating the expensive purchase of bottled water. Both water salinity and water hardness can cause damages, and since they are so closely interrelated in Colorado River water, it is not necessary to distinguish the effects of these specific constituents.

Since some water damage to household appliances or utensils has been shown to occur at salinity levels as low as 50 mg/L TDS, no particular threshold limit can be assigned. Instead, comparative statistics on useful life, from all available secondary data, are combined with selected baseline TDS values to attribute a reasonable amount of such damage to salinity of Colorado River water. This same procedure is applied to physical damages that might be incurred by water supply and wastewater treatment agencies. The fact that some damage begins to occur at very low TDS levels creates a further problem of attribution to Colorado River water, but this is basically overcome by attributing only incremental damage to the higher salinity of the Colorado River.

One new area of damage that can be confidently attributed was uncovered during research. According to data from the automobile industry, damage to cooling systems (radiators) begins at 100 mg/L TDS, and is a significant source of salinity-related economic cost. Another area of economic cost is less clearly attributable, but still closely tied to the effects of saline or hard water – the purchase of bottled water. Some data are available that delineate a relationship between TDS/hardness and bottled water purchases, but the relationship is not clear-cut because of other influences – such as advertising – on consumer behavior.

The authors approached the dilemma on causes of household damages by arraying the data on damage and useful life (where available) from previous studies of water quality-related consumer damages. These data were subjected to computer-based regression analysis which derived formulas and generated curves over the study TDS range. The annual dollar damages to households in the metropolitan areas (including business and commercial uses not related to industrial processes) using all or part Colorado River water are presented in ranges. Based on runs of the computer program, using alternated baseline salinity levels and the 1976-1985 average salinity level of the Colorado River, damage in 1986 dollars ranges from a high of $637.6 million to a low damage estimate of $156.1 million. These annual damages range from $64.76 to $108.81 per household.

Damages to Water/Wastewater Utilities

Damages to water and wastewater utilities were calculated from reductions in the useful life of system facilities and equipment, caused by increased corrosion and scale that occur in saline conditions. These damages were determined on the basis of the useful life information, population projections, and replacement cost of various treatment and distribution facilities affected by salinity deterioration. Annual damage is calculated by dividing capital investment cost per capita by useful life at a predicted TDS level. The annual cost to various Lower Colorado River Basin utilities, depending on the baseline used for measurement, is $3.2 million to $22.8 million, or from $1.34 to $3.88 per household.

Damages to Utilities from Policy/Regulation

This particular area of damage is not represented in the computer model because no historical or basinwide data yet have been found other than those presented by the Santa Ana watershed in Southern California. The Santa Ana watershed has been using Colorado River water as a substantial part of its supply for a number of years; and, since the adoption of two California Regional Water Quality Control Board regulations, the Santa Ana River Watershed Project Authority has been addressing salinity as part of its overall water planning function.

One regulation requires that water discharged from Riverside County, either in an open channel or through groundwater recharge, not exceed approximately 600 mg/L TDS. If it does, more water must be provided for dilution, the discharge must be treated, or the discharge

C-109857

must be sent directly to an ocean outfall via a brine line. Thus far, capital costs for the brine line from the upper reaches of Riverside County are $50 million. Another $30 million in capital investment is being planned. Current yearly O&M costs for the brine line are $6.1 million, and these costs will rise to $10.8 million before 2010.

The second regulation requires that the water injected into the coastal sea water intrusion barrier of Orange County have a salinity level no greater than 540 mg/L and meet drinking water standards. As a result, the entire cost of Water Factory 21 (an advanced waste treatment facility including desalinization) is attributed to salinity control. Thus the expended capital cost of $16.2 million (with an average $50,000 yearly capital expenditure) and the annual O&M costs of about $2.9 million can be considered as salinity damages.

Increasing salinity remains an issue in the Santa Ana watershed. Desalting plants are being planned or projected for future construction in three areas – with a potential capital cost of as much as $58 million and annual O&M costs up to $21 million. Two of these plants will be necessary for water supply purposes, one may be necessary to successfully implement planned water reuse programs. Finally, the Regional Water Quality Control Board has the authority and willingness to order the purchase of alternative water supplies for blending purposes. Such purchase, presumably from the California State Water Project, could cost up to $111 million per year by 2010.

From these data, an annual estimate of policy-related damages has been developed: $7,950,000 for annual capital costs and $24,600,000 for annual O&M costs, or a total of $32,550,000 annually.

Damages to Industry

The area of industrial damages from saline water is another in which insufficient data exist. However six studies list water quality criteria for different types of industrial processes. These criteria range from -0- TDS for high pressure boilers to 35,000 TDS for once-through cooling. By using data from *County Business Patterns* for the major counties in the study area combined with the projected TDS levels in the Colorado River and the current average TDS levels in metropolitan areas, it is possible to estimate salinity damages for two groups of industries – food processing and paper mills. *The Census of Water Use in Manufacturing* [1982] provides water use data for these two industrial groups in California and the Lower Colorado River Basin. Thus the industry, its location, and its average annual water use for processing and production can be estimated. The water quality criteria for such industries ranges from 500 to 850 mg/L TDS for food processing to 80 to 1080 mg/L TDS for paper mills. By subtracting the baseline (any damage that might occur without Colorado River water) from the current damage level, the amount of damage attributable to the Colorado River can be determined. The assigned levels at which damage can occur, derived from the literature, and the calculated capital investment and O&M for desalinization provide the basis for 1986 damages that occur beginning at 500 mg/L TDS. Thus the annual damages range from $6.1 to $15.8 million, as calculated using alternate baseline levels of salinity (500 mg/L and 334 mg/L) and the 1976-85 average salinity level of the Colorado River.

Summary of Salinity Damages

Previous studies, relying on even more limited data than the present study, have reported total salinity damages by category (i.e., agricultural, municipal) in terms of specific annual values or in terms of dollars of damage per mg/L of TDS. Salinity damage estimates are based on material too complex and data too insufficient to warrant selection of a single number called "economic damage of salinity." Instead, damages should be shown as a range of values that more truly reveal the uncertainty or variability resulting from the data limitations. This is the recommended format for using this research and computer model.

The total damages from Colorado River salinity range from $310.8 million to $831.1 million annually based on the 1976-85 average level of river salinity and the two selected baseline values. Figure 1 shows the annual damages based on the 10-year average salinity using the 500 mg/L base. Figure 2 shows the annual

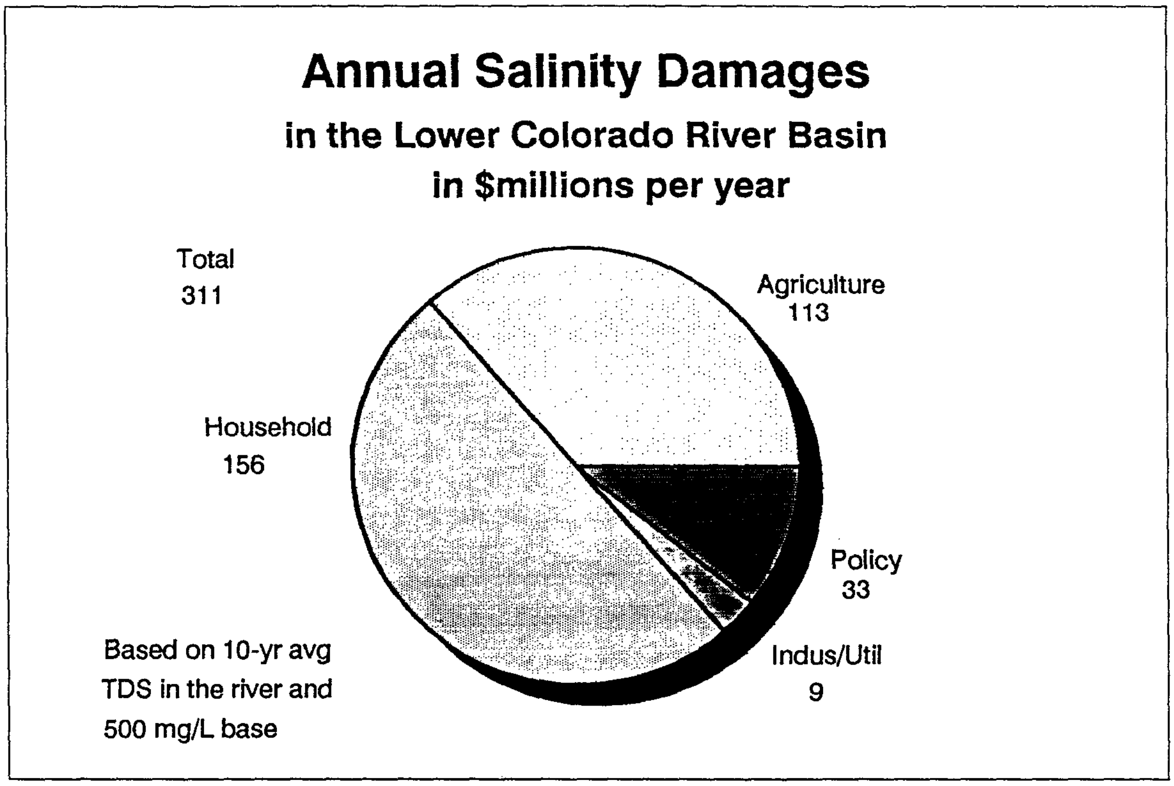

Figure 1. – Annual damages based on 10-year average salinity and the 500 mg/L base.

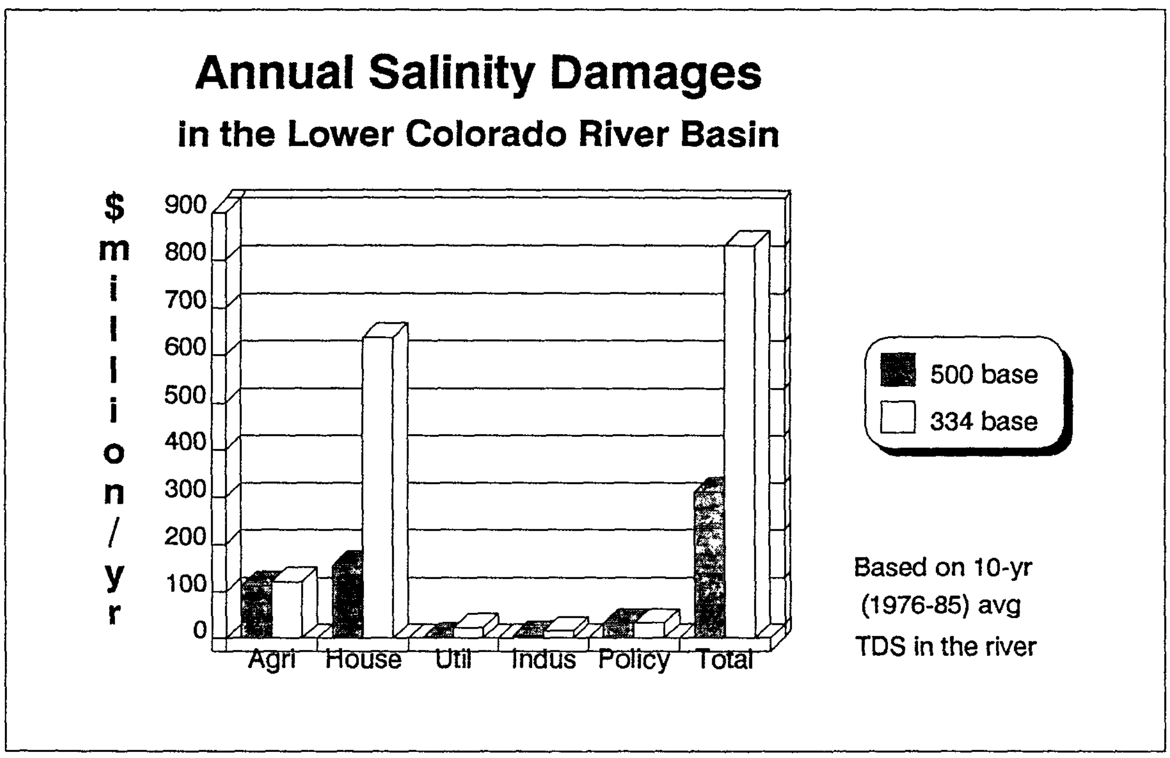

Figure 2. – Annual samages based on 10-year average salinity for both the 500 mg/L and 334 mg/L bases.

damages based on 10-year average salinity for both the 500 mg/L and 334 mg/L bases for agriculture, households, utilities, industries, policy, and the total. These annual costs may rise significantly in future years because each of several factors could lead to higher damages due to increasing salinity levels; growth in population; and growth in the rate of industrial development. This is a substantial cost, falling as it does on households, farmers, and industry in the Lower Colorado River region.

Other Issues

For most people salinity has no known health effect and may be beneficial inasmuch as drinking hard water appears to reduce hypertension to some degree. It is known that saline water, when accompanied by hardness (as is Colorado River water), can form a protective scale on water pipes, reducing corrosion and the uptake of potentially toxic metals, such as lead.

The secondary or indirect effects of salinity may positively affect economies in other parts of the country as agriculture or manufacturing shifts locations from the Lower Colorado River Basin. However, most of the damage effects will be shifts of expenditures in the economic sectors, e.g., households or industry, affected by salinity. Without better knowledge of income and budget constraints and of price elasticities – the effects are unclear.

It is known, however, that detrimental salinity effects occur in the agriculture of northern Mexico, thus creating local economic problems and international political impacts.

The Computer Program

The user-friendly computer program is designed to run on an IBM-compatible PC, with or without graphics features. It calculates four types of damages – agricultural, household, utility, and industrial – and provides these estimates in disaggregated or summary form for the entire Lower Basin. Damage estimates can be displayed and printed either in graphic or tabular form.

The program is menu driven, with internal instructions for updating input data and for running the program. The user should note, however, that while the program is easy to use, it produces damage estimates that are only as accurate as the data within it. These data represent the best efforts of the study team within the severe resource limitations of this study and are, at best, incompletely refined.

By running the program repetitively for those items whose value is uncertain, a range of salinity damage estimates will be provided that will more accurately reflect the limitations of the data. As more accurate data are developed, the results of the computer program will become increasingly refined.

Strengths, Weaknesses, Recommendations

As has been repeatedly emphasized throughout this report, a computer model (or even manual analysis) is only as good as the data that goes into it. Even so, the damage estimates presented here are believed to be substantially more accurate, comprehensive, and useful in planning salinity control measures than previous estimates have been.

Several commenters suggested that the crop yield and service life data analyses would be improved if uncertainty analyses were included. Instead of a single set of data values covering a range of TDS, a probability distribution of the results would be produced. Thus, crop damages or household damages could be accompanied by a confidence level or standard deviation value that would better reflect the range of data into the statement of final damages, i.e. \$300 million per year ± \$37 million.

The authors believe a thorough review of previous studies has been undertaken and presented in one study. Further, research programs undertaken by trade associations and manufacturers have been discovered and included in the analysis. Interest in possible future study by various industry groups has been stimulated that will directly improve both the calculation and attribution of damage from saline water (i.e., Gas Research Institute on water heaters and the automobile industry on automotive cooling systems).

The limitations of data available to this and other research studies remain the greatest weakness in estimating the economic damage of salinity in the Colorado River. Particularly in the area of industrial damages, primary research should be undertaken to reach behind the veil of industrial privacy and disregard of water costs in overall expenses. While water quality damage may, to date, represent only a small fraction of most industrial cost, it may also represent a substantial overall cost to consumers. Further research is needed on this question. Likewise, further research on policy/regulatory issues is needed to estimate the potential future impact of this area.

chapter 1

INTRODUCTION

Research Objectives

This research study was intended to update earlier research conducted for the Bureau of Reclamation beginning in 1974 and subsequently published in a 1980 report by Alan P. Kleinman and F. Bruce Brown[1] (see "Background of the Study," page 10). The present study had the objectives of:

- providing a better means of estimating present and future salinity damages under current water use scenarios and economic conditions;
- revising and clarifying earlier investigations;
- addressing unresolved questions and issues dealing with Colorado River salinity.

More specifically, this research effort consists of four interrelated studies, three that update or supplement the salinity damages data base reported by Kleinman and Brown and one to develop a computer program to estimate damages.

1. The first study updates the agricultural and municipal damages data base established by Kleinman and Brown by (a) considering current forecasts of the salinity concentration of Colorado River water available for use in the Lower Basin, including the impacts of the Central Arizona Project; (b) considering blending, water salvage and conservation scenarios that may affect future water use; (c) considering current economic conditions in terms of equipment and appliance lifetimes, costs and prices, interest rates, etc.; and (d) reexamining the threshold values previously established for municipal, industrial, and agricultural damages.

2. The second study examines and evaluates the benefits of reduced salinity of the Colorado River on reclaimed wastewater for direct and planned reuse in the Southern California water service area, as well as indirect or potential uses of such wastewater.

3. The third study investigates industrial damages due to salinity, which were not addressed in earlier investigations, and establishes representative damage estimates for various industrial water uses.

4. The fourth study involves development of a computer program that will permit easy calculation of salinity damages, by water use sector over various time periods, with varying assumptions of water use, population growth, and economic development and with the flexibility to make changes in such economic factors as costs, crop prices, and interest/discount rates.

Limitations to the Study

The Bureau of Reclamation specified several limitations to the study:

- Only direct salinity damages to the various water user sectors are to be considered. Indirect or secondary salinity damages are outside the scope of the study;
- Salinity impacts beyond the U.S. border are outside the scope of the study;
- No attempt will be made to separate water use damages according to specific ion

[1]Alan P. Kleinman and F. Bruce Brown, Colorado River Salinity: Economic Impacts on Agricultural, Municipal, and Industrial Users, Denver, Colorado: Colorado River Water Quality Office, Bureau of Reclamation, December 1980.

composition, except in industrial water use and reclaimed wastewater if such data are available; [Note: The authors have not separated municipal water use damages according to ion composition, but have discussed the complexity of corrosion which is a major cause of such damages and which is significantly influenced by the ion composition of the salinity.]

- The study will retain a basinwide perspective of control and water use areas in determining benefits or avoided damages from salinity control measures.

Background of the Study

As discussed in chapter 2 of the report, (Salinity Control Programs and Legislation), the federal government in cooperation with the Colorado River Basin States is engaged in a program of study and construction of salinity control measures in the Colorado River Basin. Although the current law establishes cost-effectiveness as the criterion for selection of salinity control projects rather than direct cost-benefit analysis, there remain public policy questions concerning the economic impacts of the salinity control program. It is important that the public, the Congress and the Administration have the best information available in determining the program's economic benefits and relative costs to weigh these benefits against their costs.

The salinity control program's economic impacts have been investigated in some depth only once, in a study begun by the Bureau of Reclamation in 1973, extended by researchers in the Water Resources Research Institutes of Arizona, California, Colorado, and Utah in subsequent years, and published in 1978 as Jay C. Andersen and Alan P. Kleinman, et al., *Salinity Management Options for the Colorado River.* A summary of this report appeared in 1980 as *Colorado River Salinity: Economic Impacts on Agricultural, Municipal and Industrial Users* by Kleinman and Brown.

In these earlier reports, the data on economic damages from salinity were expressed in \$/mg/L for agricultural damages and in \$/mg/L/household for municipal damages. These measurements are useful statistical measures. However, these damage estimates have several shortcomings:

- They are based on 1976 data which have been updated only through general price indexing using the GNP Implicit Price Deflator. This index does not reflect relative changes in the cost of water treatment chemicals, household appliances, and crops since 1976 nor does it reflect changes in treatment technology nor in consumer behavior, e.g., increased use of bottled water.

- No study of industrial damages from salinity was made because of the difficulty of obtaining the masses of data considered necessary; although the task of obtaining data for a detailed industrial damage study is indeed Herculean, the absence of even an approximate estimate of such damages is a serious deficiency in a region of continuing industrial development.

- As industrial and residential development continues, the use of water in the Basin is shifting from agriculture to M&I; furthermore, the relative economic significance of agriculture has dropped due to weak crop prices whereas the significance of salinity damages from water in M&I use is growing. The economic impacts of these shifts have not been reflected in the indexing.

- The projections of future salinity levels in the Colorado River used in the research reported by Kleinman and Brown to forecast damages[2] now appear too high. This is partly because economic development of the Basin is not occurring as rapidly as was assumed in 1976, resulting from such unexpected occurrences as the sharp turndown in oil shale and energy

[2]Kleinman and Brown calculated damages over the range of 800 to 1400 mg/L but assumed that the relevant range was 875 mg/L (the then present limit) to 1225 mg/L (the Bureau of Reclamation's former estimate of salinity at full development with no mitigation measures employed. The Bureau's 1987 projections of future salinity based on CRSS projections are shown in Figures 3, 4, and 5, page 19.

resource development in the Upper Basin and resulting slowing of economic growth. Another and more important factor is the heavy Colorado River runoff beginning in 1983 which purged significant amounts of salt from the reservoirs and further reduced salinity through dilution. This salinity improvement, while not permanent, is expected to persist for several years.

- Since 1976, greater attention has been given to the blending of Colorado River water with other waters to achieve more desirable salinity levels for M&I uses (notably in the Metropolitan Water District of Southern California [MWD] service area) and to reclamation of wastewater for reuse in industry, landscape irrigation, or in groundwater recharge. Currently, the extent of blended water supplies also is subject to the cost of power for pumping. The economic impacts of various salinity levels on the costs of blending water or treating it for reuse have not been dealt with to the desired degree in the earlier research.

For all these reasons, it appeared timely to update and supplement the data appearing in the Kleinman and Brown report so that credible and defensible estimates of current and future benefits of salinity control can be developed, with as much accuracy as the data permit. By developing a flexible, yet manageable computer program (a program suitable for use in an IBM-compatible personal computer adequate for computer graphics), future estimates of the economic impacts of salinity control can be done easily and swiftly. The program will permit ready modification of input parameters, e.g., salinity (TDS) levels, changes in crop values and in agricultural acreage planted. Moreover, shifts in water use from agriculture to M&I; changes in damage threshold levels; shifts in location of use that will occur as the Central Arizona Project matures and population changes; changes in discount rate; changes in costs of appliances, treatment processes, etc., all can be accounted for in the program.

The Rationale for Defining Salinity Damages

Earlier attempts to measure the effects of salinity have treated such effects as absolute. That is, the physical effects of salinity levels in reducing crop yields, in corroding and thus reducing the useful life of water-using household devices, etc., have been measured against an "ideal" salinity level at which no physical effect is apparent. Then these physical effects are described in economic terms, such as the value of reduced crop production and the monetary costs of more frequent replacement of washing machines, household piping, etc. Such an approach can be misleading.

This measurement of physical and economic effects of salinity in water supply against an ideal water supply appears to have been taken with little justification. It may reflect merely the researchers' belief or assumption that saline water has deleterious effects which logically should be measured against a standard of pristine water whose salinity level is below the threshold that causes measurable effects. However, such pristine water is not always found in nature and certainly is rarely found in waters that have been subjected to the impacts of human activity.

Salinity Effects vs. Salinity Damages

There is a fundamental question underlying this study, a question whose answer has a major influence on the study findings, yet one that cannot be answered solely through engineering or economic analysis. That is, which physical and economic effects of saline water should be termed "damages"? The answer is not provided from engineering, economics, chemistry or biology. There are philosophic aspects to consider. For example, the term "damage" carries with it the concept of mitigation. Rationality leads us to take steps to reduce or otherwise correct damages, particularly those which are caused by man's action or inaction, and which can be controlled or corrected at a cost that is less than the resulting benefit. Yet, merely because water is saline, it is not always appropriate to consider it as a source of damage.

Thus, the question of effect versus damage relates not only to water source, but to the cause of the salinity, the use to which the water is put, and whether the use is appropriate or well-managed. In direct answer to the question, "Should every negative salinity effect be considered a damage?," it is the judgment of the authors that each negative impact should not be, and could not be, considered a damage. Instead, the impacts of current salinity should be compared with those of a baseline salinity level that can be justified as a "normal" standard for comparison.

By using one or more selected baseline salinity levels, a potential problem is avoided: that of measuring damages against an idealized water supply that rarely exists in nature and could never be achieved technologically or economically for most water supplies. Measuring against such an ideal water would exaggerate the true damage figure. Instead, it is proposed to measure the physical and economic effects of two water supplies – one with current salinity levels and another with a selected baseline salinity level – and subtract the latter from the former. The difference in the economic effects, or costs, between two or more salinity levels has been selected in this study as the appropriate measure of salinity "damages."

Selection of a Baseline

What should the baseline be? An exploration has identified numerous candidates. Should it be the "natural" level of salinity in the Colorado River? If so, at which point in time or at which physical spot along its course of rising salinity levels should it be measured? Should the baseline be the salinity level most commonly found throughout the U.S., despite wide variations in rainfall, soil, and geology? Should it be the level which EPA recommends as a secondary drinking water standard?

Table 1 presents an array of 13 possible baseline salinity levels, ranging from under 50 mg/L (a "pristine" water that might still be chemically aggressive) to 825 mg/L, the maximum flow-weighted salinity level projected at Parker Dam in 2010 without adoption of salinity controls.

The selection of appropriate baselines has been a matter of intense discussion among the authors, with the Bureau of Reclamation, and with the Work Group of the Colorado River Basin Salinity Control Forum. Agreement was reached regarding the selection of two baselines which, in conjunction with current salinity levels would bound the range of salinity damages. They are: 334 mg/L TDS and 500 mg/L TDS. There are other salinity levels which could have been considered as baseline values, as illustrated by table 1. Some of them will be mentioned briefly following a discussion of the two selected baseline TDS numbers.

334 mg/L TDS. EPA's 1971 *The Mineral Quality Problem in the Colorado River Basin* determined a natural TDS level at Hoover Dam based on natural point and diffuse sources of 334 mg/L TDS for both 1960 and projected 2010 conditions at Hoover Dam. This is based on the 1942-1961 hydrologic record. It was pointed out that it is not entirely consistent with virgin flow and salt load assumptions used in the longer period of record of the CRSS data base.[3]

500 mg/L TDS. The EPA Secondary Drinking Water Standard of 500 mg/L TDS is widely used in reports and discussions about salinity. It is the standard widely used by various health agencies and by the Environmental Protection Agency, although this number is not based on any formal scientific investigation. It is selected as a baseline because it is a widely recognized and accepted TDS parameter in the area of water quality. The 500 mg/L standard also is the goal of the Metropolitan Water District of Southern California for its blended water supply.

Other Possible Baselines

Initial studies considered baselines of 200 mg/L TDS, 250 mg/L TDS, 295 mg/L TDS, and 349 mg/L TDS. The 200 mg/L baseline corresponded to the hardness goal (80-100 mg/L) in the AWWA's policy statement for Potable Water adopted in the 1960's (currently being revised).

[3]EPA, Summary Report, pp. 15 and 22; David Merritt, Colorado River Water Conservation District, September 15, 1987.

Table 1. – TDS levels considered for baseline and current condition assumptions

TDS in mg/L	Remarks
under 50	Distilled water, may be chemically aggressive.
186	Average TDS of water supply to 100 largest cities in the United States (1982).
200	Typical of water supplies in Upper Basin above Glenwood Springs, Colorado. Some household damages begin to be documented.
250	Rounded TDS of alternate water supply to Southern California from state project sources (1986); and probable virgin flow of Colorado River measured at Lee Ferry (based on CRSS natural flow data, 1906 - 1983).
334	Natural TDS of the Colorado River at Hoover Dam based on the 1942-1961 hydrologic record, as developed in EPA's 1971 *The Mineral Quality Problem in the Colorado River Basin.*
349	Maximum TDS of Upper Basin conditions at Cisco, Utah.
500	EPA secondary drinking water standard, a recommended but not mandatory standard, apparently selected on the basis of estimated health and taste aspects.
537	1986 reported level of water deliveries by the Metropolitan Water District of Southern California [MWD] (lowest TDS level in 42 years).
539	Estimated TDS of Colorado River in the Lower Basin with no dams, based on earliest water quality measurements (1926-1934) at Yuma, Arizona.
542	Current 1986 level at Parker Dam (provisional data).
678	Ten year average (1976-1985 at Parker Dam).
747	Salinity criterion below Parker Dam established by the Colorado River Basin Salinity Control Forum.
825	Maximum TDS projected for Parker Dam in 2010 (1987 CRSS study) without further controls.

The AWWA policy stated that hardness of 80-100 mg/L is not objectionable to most consumers. The 200 mg/L baseline also appeared to be similar to the annual average salinity of State project water delivered to MWD from the California Aqueduct (219 mg/L TDS in 1985) and to a recently reported level of TDS in the Colorado River near Glenwood Springs, Colorado.

The case that can be made for a baseline TDS level around 250 mg/L includes, with some accuracy, the possibility that it represents the level of salinity that a Colorado River completely untouched by man might have. With no dams, no irrigation projects, no diversion for any human uses, a free-flowing river with an annual average virgin flow of approximately 15 maf with a natural salt load of about 5.2 million tons at Lee Ferry (based on CRSS natural flow data, 1906-1983) represents a TDS level of 255 mg/L.[4] It is arguable that such a figure could represent the natural state for the entire length of a free-flowing river (even including the salt input from Blue Springs).

[4]These numbers were developed by David Merritt, Senior Water Resources Engineer, Colorado River Water Conservation District, based on his work developing the CRSS data base while at the Bureau of Reclamation.

In addition, 250 mg/L TDS represents the approximate average TDS of California State Project water, the most likely available alternative source of water for the majority of Lower Basin Colorado River water users. Finally, while it is recognized that some negative effects of salinity damages can start at lower TDS levels, in fact significant impacts do not occur below the range of 200-300 mg/L TDS. Thus 250 mg/L could be considered as a baseline representing a practical value for "ideal water."

The 295 mg/L baseline corresponded with historical average Colorado River salinity near Grand Junction. Finally, the 349 mg/L baseline was the most recently (mid-1986) reported level of the mainstem near Cisco, Utah, and was selected to provide a mid-point balance to the baseline range.

One other potential baseline discussed was that of 539 mg/L. This number was derived from the CRSS program by the staff of the Bureau of Reclamation. It represents a "modern" natural TDS level inasmuch as it is the salinity level of the Colorado River (measured at Yuma, Arizona) prior to construction/closure of any of the large storage reservoirs (1926 to 1934). This 539 figure does include diversions for irrigation and M&I use, and the subsequent return flows. While it in no way represents the "virgin" TDS of the Colorado River, it does represent river flow that is not particularly well controlled – thus assuming a larger proportion of natural TDS runoff than could be expected under the controlled conditions instituted by the storage reservoirs.

Selection of Current Values for TDS

During the course of this study, reviewers and advisors became as concerned about the selection of "current" TDS values as about the baseline. This appeared to be due in part to the fact that in 1986 the Colorado River had experienced an extended period of excess flows – thus reflecting abnormally low salinity levels. It also appeared to be partly due to a fear of misstating any salinity damage estimates, a concern about the lag in the reporting of salinity levels at gaging stations, and a recognition of the difficulty in estimating the actual TDS level of the usually blended water delivered to consumers in the metropolitan areas covered by this study.

The Colorado River Basin Salinity Control Forum Work Group and staff of the USBR Colorado River Water Quality Office, at a meeting in October 1987, decided to select two values to be used as "current" TDS values at each of the gaging stations used in this study. One represents the most recently available 1986 average at each station (provisional data). The other is a selected 10-year average at each station, based on CRSS data. They are shown in table 2.

Table 2. – "Current" TDS values used in the study in mg/L. [1]

	1986 Flow-weighted Actual TDS	(1976-1985) Ten-year Flow-weighted Average TDS
Hoover	542	652
Parker	542	678
Imperial	579	767

[1]provisional data

In this report, the 1986 flow-weighted salinity level is used as the "current value" together with the two selected baselines to estimate salinity damages. However, for comparison, the 10-year flow-weighted average also is used in conjunction with baseline values to produce another range of salinity damage estimates. The 10-year average is believed more representative of past and future river salinity levels than the 1986 actual TDS level.

The salinity levels of the Colorado River reservoirs behind Parker and Imperial Dams are essentially the same as that of irrigation water delivered to the major agricultural areas, i.e., 542 and 678 mg/L TDS for Riverside and La Paz Counties and the future Central Arizona Project, and 579 and 767 mg/L for Imperial and Yuma Counties. However, the values are blended for each of the metropolitan areas to represent the mix of Colorado River water and local ground or surface water supplied to water consumers.

Table 3 shows the blends for 1986 and the 10-year flow-weighted average.

Table 3. – Blends of Colorado River water and local ground or surface water.

Area	1986 Actual TDS	(1976-1985) Ten-Year TDS
Maricopa County/Phoenix	received less than 1% CO River water 1986	
Pima County/ Tucson	receives no CO River water currently	
Clark County/ Las Vegas	477 mg/L	564 mg/L
Los Angeles County	405 mg/L	450 mg/L
Orange County	505 mg/L	540 mg/L
Riverside County	535 mg/L	540 mg/L
San Bernardino County	455 mg/L	470 mg/L
San Diego County	555 mg/L	625 mg/L
Lower CO River Area[1]	579 mg/L	767 mg/L

[1]Receives its water directly from the river. The closest gaging station is at Imperial Dam and those are the TDS values used in this report.

Note: Does not include those portions of the County outside the MWD service areas in California.

chapter 2

SALINITY IN THE COLORADO RIVER BASIN

The Colorado River Basin

The Colorado River stretches 1,400 miles through the southwestern United States and northern Mexico before emptying into the Gulf of California. Its drainage basin covers a 244,000 square mile area and includes portions of the five driest states in the nation (Nevada, Arizona, Utah, Wyoming, and New Mexico), the seventh driest (Colorado), and the desert portions of California. The climate of the Basin extends from the snowpacked Rockies and high plains of Wyoming and Colorado to the arid desert of Arizona.

The water resources of the Colorado River Basin are inadequate in quantity to meet all legitimate demands for their use, even though water is customarily utilized by a succession of users as it flows downstream. The Colorado River waters currently irrigate 2.5 million acres in the Basin and thousands of acres outside the Basin through export. The river provides water for about 2.5 million people in the Basin, and through export provides full or supplemental supplies to another population of 14.5 million and irrigates hundreds of thousands of acres of farmland outside of the Basin, primarily in southern California but also in eastern Colorado and central Utah. In addition, the river supplies 1.8 million people and irrigates about a half a million acres in Mexico. Estimates from the seven Basin states indicate that California, Arizona, New Mexico, and Nevada have already or within the next several years will be fully using their Compact apportionments. The growing demands for water by metropolitan populations and potential large demand by manufacturing industries and by mineral and energy developers, in addition to the heavy dependence on water by agriculture, will cause an ever-growing gap between water supply and need. This may force both a curtailment of some demands and a reallocation of water supplies among potential users, resulting in some negative economic, social, and environmental consequences.

Colorado River Salinity and Its Causes

A companion problem to limited supply is that of water quality. The Colorado River grows naturally salty from its headwaters through the seven basin states to the Gulf of California. In the Lower Basin states (Arizona, Nevada, and California) and in the Republic of Mexico, salinity can reach levels that reduce the river's usefulness and cause economic penalties to many water users. As expected economic development continues, salinity will increase unless offset by salinity control measures to remove over one million tons of salt per year from the river.

Nearly half (47 percent[5]) of the river's salinity occurs naturally as the river and its tributaries dissolve minerals and salts from river beds, receive runoff that has transversed saline land, and are fed by saline springs and groundwater returns. The hot dry climate increases river and reservoir evaporation, further concentrating these salts. Even without the development created by man, the Colorado would remain saltier than most other rivers in this country.

Irrigated agriculture is the major man-created contributor to Colorado River salinity

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[5]U.S. Department of the Interior, Bureau of Reclamation, Colorado River Water Quality Office, Status Report: Colorado River Water Quality Improvement Program, Denver, Colorado: author, January 1983, p. 4.

(37 percent). Irrigated farming leaches salts from the saline soils found in the Basin.

The salinity of the Colorado has both regional and national implications. Regionally, irrigation of crops with excessively saline water may reduce yields or even prohibit growing of certain types of crops. Domestic use of saline water can require extra treatment to meet secondary drinking water standards (500 mg/L) or to improve palatability for drinking or cooking. Saline water can also damage plumbing and utensils and affect discretionary purchases of householders. These regional penalties of saline water use are described and quantified in subsequent chapters of this report.

Nationally, the impact of Colorado River salinity affects our relations with the nation of Mexico. Minute 242 of the International Boundary and Water Commission of the United States and Mexico addressed the problem in 1973 with the result that the United States agreed to deliver an average of 1.36 maf of Colorado River water each year at Morales Dam which is at an average annual salinity no greater than 115 ppm ± 30 ppm more than that measured at Imperial Dam.

Salinity Control Programs and Legislation

The Bureau of Reclamation began a general investigation program (Colorado River Water Quality Improvement Program) in 1971. The next year, a cooperative program was undertaken by the Departments of the Interior and Agriculture, the U.S. Environmental Protection Agency (EPA), and the seven states of the Colorado River Basin to maintain salinity levels at or below the levels then existing on the Colorado main stem.

Three major legislative acts subsequently have defined and implemented this broad salinity control program. In 1972, Public Law 92-500, the Federal Water Pollution Control Act as amended ("The Clean Water Act") was interpreted by EPA as requiring water quality standards for salinity in the Colorado River.

In 1973, the Colorado River Basin Salinity Control Forum was organized as a mechanism to establish salinity standards and to promote interstate cooperation in the Basin and, among other purposes, to develop numeric criteria and a plan of implementation for salinity control for the river, to be recommended to each state for its adoption.

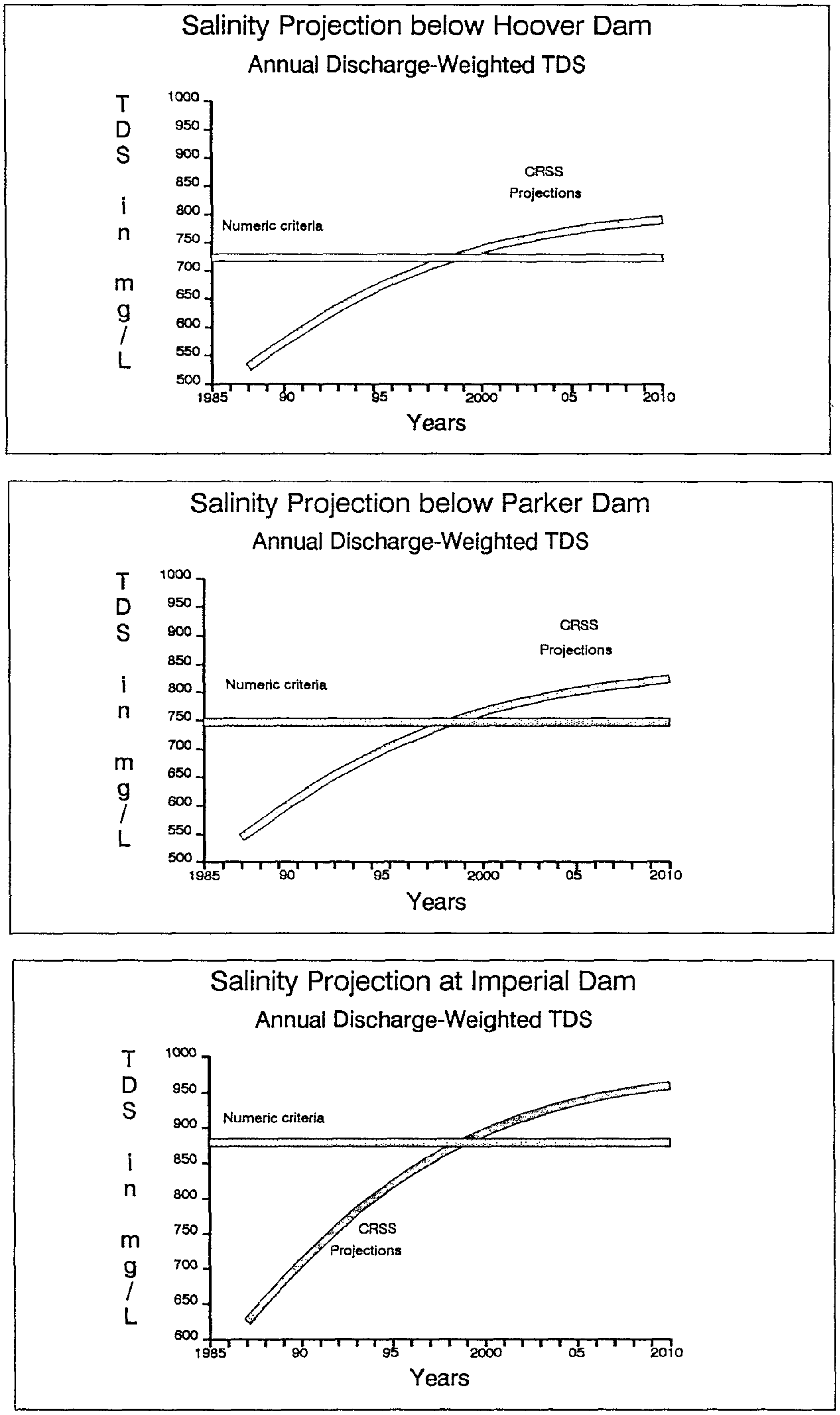
Subsequently, the seven Colorado River Basin (CRB) states adopted the criteria and a plan of implementation for maintaining salinity at the numeric criteria for Hoover, Parker, and Imperial Dams and the EPA approved the plan.

In 1974, Public Law 93-320, the Colorado River Basin Salinity Control Act, established the Colorado River Basin Advisory Council, made up of representatives of the seven Basin states, to make recommendations to the three named federal agencies of the progress of implementation of the program. P.L. 93-320 also authorized construction of four salinity control units and studies of another twelve units.

In 1984, the Congress passed Public Law 98-569, amending P.L. 93-320. The amended law authorized two additional salinity control units and directs the Secretaries of the Interior and Agriculture to give preference in construction to those salinity control projects that reduce salinity at the least cost per unit of salinity reduction. A major component of the Act was authorization of a voluntary onfarm program within the USDA program.

Past and Anticipated Future Salinity Levels of the Colorado River, 1973-2010.

The Bureau of Reclamation in 1985 developed the data shown in Figures 3, 4, and 5, Salinity Projections at the three stations for which numeric criteria have been adopted. These graphs illustrate flow-weighted average annual estimates of salinity levels (in mg/L of total dissolved solids) at each of three major points of diversion along the Colorado River, i..e., Hoover, Parker, and Imperial Dams. Both the past and future salinity values are flow-weighted average annual estimates. Future estimates have been developed by simulation using the Colorado River Simulation System (CRSS).



Figures 3, 4, and 5. – Salinity projections below Hoover, below Parker, and at Imperial Dam without further controls.

Salinity concentrations at Imperial Dam decreased steadily from 1970-79, reflecting a buffering of annual fluctuations in salinity caused by nearly 50 million acre-feet (maf) of reservoir storage. Salinity dropped notably in 1980 as Hoover Dam discharges increased to 11.1 maf, diluting the salinity at Imperial Dam temporarily. With more normal flows in the river in 1981 and 1982, the salinity levels rebounded slightly. Higher releases from Hoover and Glen Canyon Dams in 1983 and 1984, caused by record breaking reservoir inflows, caused salinity at Imperial Dam to drop again. With nearly 50 maf of high quality water in storage, salinity at Imperial remained relatively low in 1985 and 1986.[6]

The salinity projections between 1987 and 2010, shown in Figures 3-5, result from projections of depletions and salt pickups caused by Colorado River Basin development. These projections are based on the historic water supply and on estimates of future depletions of water from the Upper and Lower Basins reflecting irrigation, transbasin diversions, municipal and industrial uses, evaporation, and uses in mineral development.[7]

The steady increases in salinity levels forecasted in Figures 3-5 are based on the level of development anticipated to occur by 2010. At that time, the salinity at Imperial Dam is expected to reach about 963 mg/L of total dissolved solids (TDS). The computer programs used in the CRSS are based on certain assumptions: complete mixing, steady-state transport of both water and TDS, and no losses of salinity due to chemical precipitation or salt stratification within the river/reservoir system.[8]

Salinity of Metropolitan Water Supplies in the Lower Basin

Determination of the TDS level of delivered municipal and industrial water supplies in the lower Colorado River Basin is difficult at best. Much of the water used is a blend of Colorado River water and other water supplies – groundwater, surface water from northern California or from the Salt and Verde Rivers, etc. In addition, salinity is not regularly monitored under local water quality regulations and is therefore measured only infrequently. Records of TDS levels usually are not found charted with consistency. Further, the number of water purveying agencies in the Lower Basin is several hundred, each with different sources of supply, blending activities, and reporting standards. Typically, TDS levels vary geographically within a water supply agency's service area, and also vary over time due to fluctuations in distributing supplies from different sources with different TDS levels. The best any researcher can do without months of detailed record searches is to sample and estimate the average systemwide TDS for some major metropolitan areas and for a few subareas within them.

This is the approach selected for this study, primarily because of constraints on project resources. In Arizona and Nevada it is possible to estimate what the future blend of water might be since Colorado River water will be added to existing and well-identified local water supplies. In southern California, estimates of future blended water are not possible because of the uncertain status of State Water Project supplies that will be imported from the north, and because of the more complex possibilities involved in blending and distributing water from the Colorado River and a variety of local surface and groundwater sources. More or less use of State water will affect the ultimate TDS level, as will the future quality of such State water.

Table 4 provides the best available data on current and (where possible) estimated TDS levels for the bulk of the municipal and industrial water supply in the lower Colorado River Basin. It should be noted that 1984-85 was a period of unprecedented high flows in the river,

[6] A more complete discussion of historical and current salinity conditions in the Colorado River can be found in Part V of Department of the Interior, Quality of Water, Colorado River Basin, Progress Report No. 12, Washington, D.C.: January 1985, pp. 23-29.

[7] Details of future development assumptions on which the salinity projections are based can be found in ibid., pp. 30-60.

[8] Details of the CRSS and the assumptions on which salinity projections are based can be found in ibid., pp. 100-105.

Table 4. – Current or estimated TDS levels of M&I water supplies in the Lower Colorado River Basin.

Metropolitan Area		TDS
San Diego County *	1986 estimated blend (90% from MWD)	579
Riverside Co. *	1986 estimated blend	535
Orange County *	1986 estimated blend	505
San Bernardino *	1986 estimated blend	455
Los Angeles *	1986 estimated blend City/County average	405
Phoenix	current valley average	400-500
Tucson	current valley average	400-500
Las Vegas Valley	1986 groundwater	235-250 **
	1986 Colorado River actual	542
	1986 blend	577 **

* Does not include those portions of the County outside the MWD service areas. More recent numbers are 310 and 499, respectively, but they were not available when the computer program was developed.

causing record low salinity levels. As the river returns to more normal flows, the TDS at Parker should return to around 700 mg/L.

The current TDS averages make it clear why San Diego, Riverside, and Orange Counties in southern California are the three areas most actively concerned with salinity. There are other areas or subareas that have higher and much higher average TDS levels (such as Buckeye and parts of Chandler, Arizona), but Riverside and Orange Counties are part of a major metropolitan area as well as part of the Santa Ana River watershed which exhibits substantial incremental salinity as it reaches Orange County. Further, the Santa Ana Region Water Quality Control Board has established firm policies on salinity which have mandated both structural and management actions on the part of area water suppliers. The responses of Riverside and Orange Counties to increasing salinity can serve as a general model for future activities in other areas of the Lower Colorado River Basin.

Salinity, as this report discusses, is an economic water quality issue – not a matter of serious concern for human health. In this sense salinity becomes a water quality parameter that is subject to policy and cost decisions unlike the decisions mandated by the presence of TCE or nitrate pollution exceeding primary drinking water standards. The fact that salinity is primarily a management problem may also explain why so little regulatory concern has yet been exhibited by cities and states in regularly measuring or addressing TDS in water supplies.

chapter 3

ECONOMIC DAMAGES TO IRRIGATED AGRICULTURE

Salinity Damage Threshold of Crops

The salt tolerance level of plants—both food crop and ornamental—varies greatly according to a number of conditions of which the level of salinity in irrigation water is but one. Climate, farming practices, soil conditions, and the constituent makeup of minerals in irrigation and soil water all contribute to the tolerance, or lack of tolerance, of most commonly farmed crops to the presence of salt. In this study the primary interest is in the effect of the TDS level of Colorado River irrigation water on crop yields. E.V. Maas, Research Leader at the U.S. Salinity Laboratory in Riverside, California, has devoted a career to examining the salt tolerance of crops. His latest work, published in 1986, updates the results of more than 20 years of study and provides us with relative guidelines on the tolerance of crops to differing degrees of soil salinity as measured in deciSiemens/meter (dS/m) of electrical conductivity of saturated soil extract. Maas cautions that "soil salinity is seldom constant with time or uniform in space." But, he adds that the most recent evidence indicates that the critical area is, for areas of frequent irrigation, the upper part of the root zone where "soil salinity is influenced mostly by the salinity of the irrigation water." His salt tolerance tables are prepared for this upper zone at the threshold level above which "yield decreases approximately linearly as salinity increases."

Keeping Maas' caution in mind that threshold salinity levels are only approximate because growing conditions can vary so dramatically, it is possible to convert the levels of soil electrical conductivity to TDS levels in irrigation water by using a formula presented in *Irrigation with Reclaimed Municipal Wastewater.*[9] In that formula, TDS is empirically related to electrical conductivity of the saturation extract (represented as dS/m) multiplied by 640. The electrical conductivity (salinity level) of the irrigation water, as it relates to soil saturation, can be determined by dividing the soil saturation level of TDS by 1.5. (For example, if the soil extract threshold level of carrots is 1.0 dS/m, multiply the 1.0 x 640 to convert to TDS and divide the result [640 in this case] by 1.5 to obtain the TDS equivalent for irrigation water of 427 mg/L.) Thus the threshold levels for TDS in applied irrigation water, as identified by Maas, are shown in table 5.

Table 5. – TDS threshold levels in applied irrigation water
Source: Maas

Crop	TDS	Crop	TDS
Lettuce	555	Alfalfa	853
Cotton Lint	3285	Grapes, table	640
Carrots	427	Cantaloupe	1422
Wheat	2560	Dates	1707
Oranges	725	Sugar Beets	2987
Grapefruit	768	Lemons	768
Onions	512	Beans	427
Corn	726	Cabbage	768
Celery	768	Peppers	640
Potatoes	725	Spinach	853
Strawberries	427	Sweet Potato	640
Almonds	640	Berries/Plums	640
Peaches	725	Avocados	427

[9] University of California, Davis. Department of Land, Air and Water Resources. Irrigation with Reclaimed Municipal Wastewater: A Guidance Manual. Sacramento: State Water Resources Control Board, July 1984, Appendix H, page H-2.

While these tolerance levels must be considered as estimates and should serve only as a general guide, research into crop yields in the lower Colorado River Basin indicates that such thresholds are not unreasonable. It is noteworthy that the U.S. Soil Conservation Service classifies soil salinity in the upper soil layer (above 8 inches) as slightly saline if the saturation level is less than 4,000 micromhos per centimeter (µmhos/cm) – about 2,560 mg/L TDS, showing how the differing requirements of the soil-water users can lead to different kinds of definition for soil salinity.

Salinity Effects on Crop Yields

While Maas has determined approximate threshold levels above which salinity damage may begin, Dr. James Rhoades, also of the U.S. Salinity Laboratory in Riverside, has set himself to the task of dealing with growing crops in salty water or soil. While his test programs often require the availabilty of very high quality water during germination (water not available to farmers in the Lower Colorado Basin), he has tested a variety of crops with a variety of more readily available farm management practices to conclude that it is possible to grow crops at much higher salinity levels present in irrigation water and soil than previously thought possible. The historical record of crop yield per acre seems to support the position of Dr. Rhoades that some crops can be grown with fairly salty irrigation water.

Crop production at higher salinity levels presupposes fairly sophisticated irrigation and management practices. In reality, only 20 percent of the Imperial Irrigation District is under sprinkler irrigation. Throughout that area and in much of the Lower Colorado Basin, flood irrigation is still the method of choice, since it requires less capital investment and lower operation and maintenance costs than sprinkler irrigation. However, flood irrigation is more difficult to schedule at the precise time demanded by the condition of the soil water, so crop yield may be reduced compared with yields using sprinkler irrigation. Moreover, highly saline water, under flood irrigation, requires more frequent applications to accomplish needed leaching. The more frequently a farmer must irrigate, the higher are his labor costs.' Since so few farms are automated, farmers are very happy with water below 600 mg/L TDS since it requires many fewer labor-intensive irrigations.

Other Factors Affecting Crop Yields

Clearly, salinity can affect crop yield, according to the U.S. Department of Agriculture. Most farmers and agricultural agents agree. A former Imperial County Agricultural Commissioner states that lower TDS levels increase the suitability of soil structure for crops and allow for better leaching and thus a more complete use of irrigation water for crop growth. Yet, as Maas reiterates, it is not clear at what precise salinity level crop yield is affected. There appears to be an inverse relationship between yield and salinity levels in the period 1971-1984 but this relationship is far from regular. What relationship can be drawn between TDS and yield is subject to distortion by the other factors, such as variations in rainfall and temperature, the presence of pests, and variations in farm management practices.

Economics of crop prices also can affect yield, as a former County Commissioner points out. When market prices are down, not all crops are harvested, thus skewing the acreage yields reported in some places.

Recognizing that these other factors affect the salinity/yield relationship, it is believed that their impact can be largely overcome by use of empirical data from all of the major agricultural counties in the Lower Colorado River Basin over a period of 14 years (1971-84) which will include variation in climatic conditions, market conditions, and farm management practices throughout the region.

Estimating Current and Future (1987-2010) Salinity Damages to Agriculture

For purposes of estimating current and future salinity damages to agriculture from use of Colorado River water for irrigation, an empirical model was developed which relates crop losses to the differential yield that can be expected at two levels of salinity: the first, a baseline level below the threshold of salinity damage from the crop in question; and the second, the actual level that can be expected from the USBR simulation of river conditions (projections shown on figures 3-5, page 19).

Next, twelve crops were selected that represent the highest value crops in the irrigated farms of the Lower Basin, and which have salinity damage thresholds within the range of 200-1200 mg/L, as determined by E.V. Maas of the U.S. Salinity Laboratory. The highest value crops were identified from the most recent (1985) Bureau of Reclamation *Summary Statistics, Vol. I Water, Land, and Related Data*. They are: lettuce, alfalfa hay, cotton lint, wheat, sugar beets, carrots, cantaloupe/melons, oranges/tangerines, lemons/limes, grapefruit, table grapes, and dates. However, five of these crops were excluded because their salinity damage threshold exceeds 1200 mg/L: cotton lint, wheat, sugar beets, dates, and cantaloupe/melons. Two other salt-sensitive crops of relatively high value were added: onions and avocados.

Regressions on Yield of Agricultural Crops

Data on crop yield of nine salt-sensitive crops in three agricultural counties where Colorado River water is used for irrigation were obtained by year for the 1971-1984 period from Arizona and California agricultural statistics. The counties were Yuma, Arizona; Imperial, California; and Riverside, California. La Paz County, Arizona, had been created only in 1983, so data were sparse and therefore not included. The data show average yield of each crop in conventional units of yield (e.g., tons or cwt) per acre.

Data on salinity levels in the Colorado River at Imperial Dam and at Parker Dam were obtained for each of the years from the Bureau of Reclamation's *Quality of Water, Colorado River Basin, Progress Report No. 13*, January 1987, Tables 19 and 20. During the 1971-1984 period, TDS values ranged from 675 to 892 mg/L at Imperial Dam and from 611 to 758 mg/L at Parker Dam.

These data were combined into data sets (yield vs. TDS) and regression curves and formulas generated using the computer regression program. For six of the crops, data from all three counties were available, although Yuma County data on citrus crop yield (i.e., oranges/tangerines, grapefruit, and lemons/limes) were available only for the 1980-1984 period. For carrots, yield data were available only for Imperial and Riverside Counties. For avocados and table grapes, yield data were available only for Riverside County.

By combining data from three counties, the implicit hypothesis was made that salinity is the sole factor determining yield, and that other factors such as climate, local rainfall and temperature variations, soil quality, and farming techniques are uniform among the counties. Such simplification is known to be untrue, so the yield data being regressed against salinity are believed to provide only an approximation of the true yield/salinity relationship. Nevertheless, no better data are known to be available for use in this study.

The use of an empirical TDS/yield relationship based on actual crops grown and on such profit maximizing adjustments in agricultural techniques as were made in the Lower Basin during the 1971-85 period parallels the reasoning of Richard Gardner, who calculated annual salinity damages "as the difference in net income between the two salinity levels, that is, the amount by which profits are reduced after all profit maximizing adjustments have been made to the higher salinity level."[10]

For some crops, inspection of the data shows that crop yields from the desert portion of Riverside County are lower than those in Imperial and Yuma Counties, even though Riverside County receives Colorado River water from below Parker Dam which is less saline than water from below Imperial Dam. Such an inversion causes illogical regression results, e.g., that carrot yield is directly (not inversely) proportional to salinity

[10] Richard L. Gardner, "Economics and Cost Sharing of Salinity Control in the Colorado River Basin," Ph.D. dissertation, Agricultural and Natural Resource Economics Department, Colorado State University, Fort Collins, Fall 1983, p. 124.

level. These data problems were reduced by selectively dropping certain aberrant data sets from the regression analysis. In deciding which data to retain and which to drop, primary emphasis was given to data from Imperial County, California, because it represents a very large share of all salinity damages (93 percent of all damages at 800 mg/L according to Kleinman and Brown).[11]

A computer program was created specifically to calculate a series of regression formulas from experimental data on agricultural crop yields against salinity level. The computer program allows the user to enter up to 39 data sets, i.e., coordinates, and then determine a series of polynomial regression formulas, ranging through polynomial 1 (linear), polynomial 2 (quadratic), polynomial 3 (cubic), polynomial 4 and polynomial 5. In each case, the program calculates the regression curve of best fit, then calculates a Goodness of Fit Criterion to permit the user to compare the various regression curves to determine which polynomial curve best fits the data sets. The program displays a plot of each curve and, with an on-line printer, provides a printout of the regression formula, the Goodness of Fit Criterion, and the plot of the regression curve. An example of a regression curve is shown in Figure 6.

The plotted curves extended only through the range of TDS levels in the experimental data, i.e., 611-892 mg/L. There is no reason to assume that the curve formulas could be extrapolated at either end of this range, so a judgmental extrapolation was used to extend the computer-plotted curve through the entire range of 200-1200 mg/L TDS. The curves tended to be flat in the range from 200 mg/L to the approximate threshold of salinity damage determined by E.V. Maas, then dipped in the range from the damage threshold to 1200 mg/L. This nonlinear nature of the salinity function had been expected, based on the earlier work of Kleinman and Brown as well as the work of Gardner, who noted that Kleinman and Brown found average salinity damages per mg/L in the 900-1400 mg/L range to be

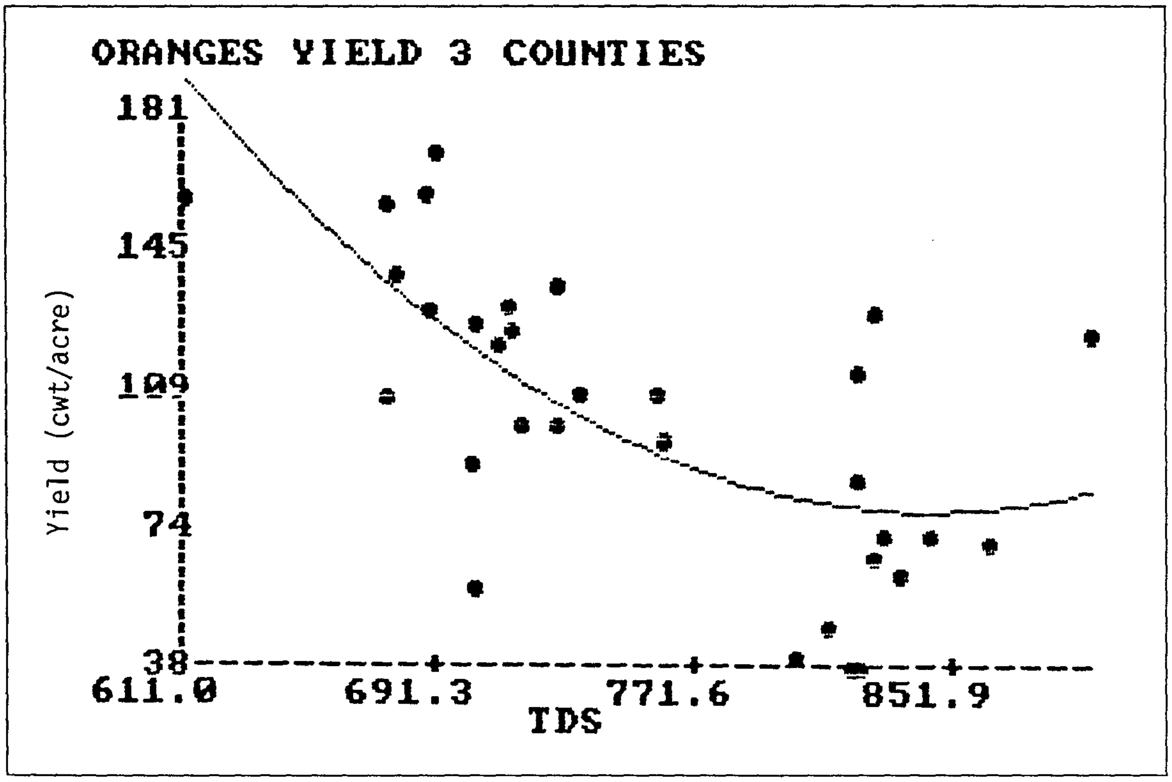


Figure 6. – Regression curve of yield of oranges/tangerines vs TDS level.

[11]Colorado River Salinity, p. 8.

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about 3.5 times higher than average damages in the 800-1100 mg/L range. Gardner comments that, "This higher estimate serves to illustrate the nonlinear nature of the salinity function. Salinity damages increase as salinity increases, . . ."

The regression formulas for yield vs. salinity are as follows, with coefficients rounded (y = yield; t = TDS in mg/L):

Lettuce: $y(\text{cwt/acre}) = 298.60 - 9.36(10^{-2})t$
Alfalfa hay: $y(\text{tons/acre}) = 9.34 - 2.39(10^{-3})t$
Onions: $y(\text{cwt/acre}) = 367.19 - 9.05(10^{-2})t$
Carrots: $y(\text{cwt/acre}) = 681.56 - 0.421t$
Oranges/Tangerines: $y(\text{cwt/acre}) = 155.51 - 0.351t + 2.09(10^{-2})t^2$
Lemons/Limes: $y(\text{cwt/acre}) = 191.09 - 8.46(10^{-2})t$
Grapefruit: $y(\text{cwt/acre}) = 561.42 - 0.561t$
Table grapes: $y(\text{tons/acre}) = 16.70 - 1.60\,(10^{-2})t$

No meaningful regression formula was obtained for avocado yield because of limited data.

Computer Model Calculations of Agricultural Damages

Data on yield/TDS relationships for the nine salt sensitive crops have been taken from the extrapolated regression curves and entered in the computer program input data. The computer program will display these TDS/yield relationships for each of the crops, and will permit the user to modify these data if better data become available. The program also displays data on various geographic areas using Colorado River water for irrigation:

- Central Arizona Project, AZ
- Yuma County, AZ (includes Gila Project, Yuma Mesa, and Wellton-Mohawk Divisions)
- Imperial County, CA
- Riverside County, CA (includes Coachella Valley and Palo Verde Irrigation Districts)
- LaPaz County, AZ (includes Colorado River Indian Reservation)

The program also includes a "Future Agricultural Area," i.e., a space for potential future expansion of the program. The program also permits any of the areas to be eliminated, e.g., the Central Arizona Project for those years before Colorado River water is delivered. The program displays, for each of the above listed areas, data on current and baseline TDS levels (as selected by the user), unit value of each crop, and acreage planted in each crop. The program permits each of these values to be updated as new data become available.

The program automatically calculates economic damages for each crop for each area, for various selected future years. For agricultural forecasts it is not expected that anyone can accurately forecast future crop acreages or future crop values. However, provision is made for such changes if desired by the user. Otherwise the current (1986) and future damages will be based on 1985 crop prices, on 1984 crop acreages planted, and on the differential yields in crop between a forecasted TDS level (from Figures 3-5) and a selected baseline TDS level. The program does not take into account management practices, market impacts, or natural forces such as pests, floods, or drought.

Other Agricultural Costs Related to Saline Irrigation Water

The authors of this report have attempted to obtain estimates of economic damages to agriculture, other than those resulting in decreases of crop yield. These other forms of damage include:

(a) loss of crop value because of removal of land from production as a result of salt build-up from irrigation with saline water;

(b) costs of extraordinary agricultural practices required to compensate for salinity, such as installing tile drains, cleaning drains, and adopting such farm practices as land levelling, sprinkler/drip irrigation, etc., when such adoption is due to salinity alone and not other economic factors;

(c) losses in crop production value due to necessary shifts fom non-tolerant high-value crops to lower-valued salt-tolerant crops.

Research on these topics, including interviews with county agricultural commissioners, project directors, irrigation district officials, agricultural scientists, and area farmers have not developed information that permits quantitative measures of these types of damages. That is, most (although not all) of those interviewed indicate that salinity of irrigation water is **one** of the reasons that farmers install tile drains, adopt expensive farm management practices, and perhaps shift cropping patterns.

While data on the costs of such practices often can be estimated, the problem is one of attribution. None of the interviewees, regardless of their degree of expertise, was willing and able to estimate the percentage of damage caused particularly or only by salinity of irrigation water because several other factors contribute to incurring these expenses. Regrettably, published research on the relative importance of saline irrigation water versus other causes of these damages is absent or insufficient to establish a basis for estimating the amount of damage attributable to salinity.

The authors' findings from the research that was possible with the resources of this study are described briefly below in the hope that they may contribute toward a future study that might answer the questions of damage estimation and attribution.

Removal of land from production.
Interviews revealed a consensus that little or no land is taken out of crop production because of salt build-up from irrigation water from the Colorado River. With proper drainage and management practices, land can be (and has been) maintained in salt balance. In fact, salt poisoning is more likely to occur on idle land. Land which has never been irrigated can be reclaimed by standard farm practices and installation of drain tiles, although some land is just not suitable for any type of agriculture.

Land is taken out of agricultural production for a number of reasons that are unrelated to salt. Some land is turned over to development of cities and towns. Other land is withdrawn from production because of surplus-crop farm programs. Still other land becomes uneconomical to farm in the current agricultural market.

Additional costs of extraordinary farm management practices.
The farmers of the Lower Colorado River Basin face a conundrum – a continuing problem. In order to farm in the desert, one must irrigate, but irrigation of desert land requires special techniques, including installation of artificial drainage. Further, desert land and its underlying water tables tend to have limitations which require particular irrigation techniques. Finally, there is insufficient native water in the Lower Colorado River Basin, so irrigation water must be imported, and the only available water for irrigation is the Colorado River which tends to be slightly saline even in its natural state.

If the costs of installing artificial drainage were due only to the salinity of the imported water, they could be readily estimated and attributed, but this is not the case. For example, in the Imperial Irrigation District, 40,000 miles of drain tiles are in place. Tiling, which controls a brackish water table and reduces the accumulation of salts in the soil profile, started before World War II and became increasingly common since 1950. The farmers in the district are adding additional tile lines between existing lines to compensate for increasing salinity in previously drained areas. The estimated cost for the original tile in place, according to a former Imperial County Agricultural Commissioner, was $150 per acre. However, to obtain adequate tile coverage in 1987 in the Imperial Irrigation District, it was estimated to cost $850 per acre. This does not include other factors that contribute to the successful operation of the drains, such as plowing or deep tillage. These costs of installing tiles, and of operations to effectively drain the soil, clearly can be attributed to salinity, some portion of which is due to the salinity of the imported irrigation water. However, no scientific data on this relationship are presently available and neither the irrigation district managers or active farmers interviewed are willing or able to make attribution or distribution of costs among saline irrigation water, groundwater salinity, soil structure, or other factors.

Additionally, as one official for the Imperial Irrigation District describes it, tiling is also a method of land reclamation – a way to reclaim the land from the multiple deteriorating factors of use, climate, groundwater and irrigation water. Tiling is used to reduce the high saline water table which has a detrimental effect on soil structure and thus on crop production. The saline groundwater also is drawn upward toward the root zone through capillary action damaging seedlings and even some mature plants. Tiling also serves to keep land in production since salt poisoning is most likely to occur on idle land due to increased capillary action drawing the saline water to the surface.

One irrigation district official says that land levelling and sprinkler irrigation are increasingly being used to obtain better use of the water and to avoid problems with soil capillary action bringing salt into the root zone.

Lengthy conversations with irrigation district officials, project managers, and farmers in Imperial, Riverside, and Yuma Counties generally support this position. It was consistently pointed out that all irrigated agriculture requires draining (at least in the American southwest), whether by installed systems, wells, or nature. In the Lower Colorado River Basin, nature provides very little drainage, so man has intervened with tiles or wells. This same type of logic applies to other types of advanced farming practices such as land levelling (level land being easier to irrigate using flood or furrow irrigation).

The costs of drain tiles and the resulting O&M, land-levelling, removal of land from production and the type of crops planted have often been attributed to saline irrigation water without any scientific or empirical study to support the attribution. However, drain tiles also serve to aid water conservation by reducing the amount of water application required to maintain salt balance, and soil conservation by reducing opportunities for capillary action.

Other types of farm management costs have been attributed by some to saline irrigation water, e.g., installation or use of sprinkler irrigation systems for crop germination and limited use of drip irrigation systems. Farmers have also made some soil modifications to the soil profile through additions of organic matter, the use of chemicals, and mechanical methods. These soil modifications could, in part, be attributed to salinity.

Although these remedies are expensive, often labor intensive, and subject to climatological effects or technological breakdown, these improvements likewise cannot be directly tied to saline irrigation water. Rather these practices appear to form a part of good farm management for the area, some undefined portion of which can be attributed to increasingly saline irrigation water.

One Palo Verde Irrigation District farmer says that "salt is a miniscule damage," possibly because PVID has better soil drainage than the other major farming areas in the Lower Basin. But, out of all the farmers and officials interviewed over the course of 18 months, only one farmer was willing to directly attribute some costs to salinity, and he could not give any clearly linked or defined costs. While having some germination problems caused by soil salinity in combination with high temperatures or heavy rain, and using portable sprinklers for germination at a cost of $125 per acre, he still finds the relationship between saline irrigation water and non-crop damages to be "pretty subtle." Drainage is clearly needed for farming in the area, but he and all the other district officials and farmers are unwilling to say what percentage of the related factors (soil, groundwater, weather, irrigation water, etc.) is responsible for each type of farm practice.

Losses in crop production due to shifts in cropping patterns.

Although increased salinity may have caused some changes in cropping patterns, for example, reducing the acreage planted in salt-sensitive crops, not all changes in cropping pattern have occurred solely because of salinity. Many of the truck-garden type crops – beans, fresh tomatoes, other vegetables – have been given over to Mexican producers because they are too labor intensive and therefore too expensive to grow in the current U.S. farm labor market.

The annual reports published by the Imperial County Agricultural Commissioner also make repeated references to factors other than salinity affecting cropping patterns. A major factor is changing crop prices. For example, in 1980 the market was "disastrous" for lettuce while the costs of production continued to increase at a record pace, so lettuce acreage dropped. In 1984 the cotton market was in decline and sizable areas of lettuce were planted in Arizona instead of in California. In 1982

Imperial County farmers faced not only water problems, but problems with new types of agricultural pests.

An irrigation district official stated that crop patterns have consistently improved since 1946 because of the tiling program's improvements to the soil despite the increasingly saline irrigation water. It was noted that in the last 30 to 40 years, the Imperial Irrigation District has been putting more salt into the Salton Sea than it has been importing via irrigation water. Thus it is by no means clear what proportion of cropping pattern change is due to saline irrigation water and resulting increases in soil salinity, in contrast to economic factors and other non-farmer controlled forces (such as pest or excessive heat or rain).

The various officials and farmers interviewed in the area did not agree about what constitutes excessive salinity in terms of attributing damages. They were unable to quantify which problems are caused by high groundwater and/or saline irrigation water. In fact with the high groundwater in the area of Wellton-Mohawk, the quality of the irrigation water (as long as it doesn't poison crops) is basically insignificant to other farm operations. Yuma Project's assistant director bluntly states that what is needed most is more water, not necessarily a higher quality water. Attribution of agricultural costs, other than non-crop production costs appears to be too complex to be categorized by cause such as saline irrigation water, unusually heavy rains, high groundwater, etc., without further study.

chapter 4

ECONOMIC DAMAGES TO HOUSEHOLDS FROM MUNICIPAL WATER SALINITY

Corrosion and Hardness Creating Household Damages

Starting with Black and Veatch in 1967, previous studies[12] of water-quality-related consumer costs have focussed on damages to water-using appliances in households and water and wastewater pipes, increased usage of detergents, and deterioration of clothing and other textiles. With the exception of the Orange County report,[13] these studies related damages to salinity (TDS) presumably because it was the most widely used measure of water quality constituents that were known to cause household damages, primarily through corrosion but also from scale deposits. To quote Black and Veatch: "In a particular water supply, it is impracticable to determine the specific effects of minerals alone, since the effects are dependent not only upon the relative content of individual minerals but also upon many other characteristics of the water. Considerations of mineral effects in this report are only broadly applicable, and overall conclusions reached do not necessarily apply in specific situations."[14]

In 1978 a Southern District report of the California Resources agency stated: "Clearly, water quality affects the domestic consumer's water use cost, but because there are many water quality parameters which are often interrelated, it is difficult to assign cost to any particular water quality factor."[15] These two caveats, written eleven years apart, reflect the concerns of many of the chemists and scientists interviewed during this study. That is, the assumption of a linear relationship between TDS and the economic value of various types of household damages presents a misleading picture of a very complex situation.

Corrosion.

The corrosivity of water has been the subject of textbooks, handbooks, articles, and studies. The most recent, a chapter in a handbook prepared by Montgomery Engineers,[16] states that "The rate at which corrosion takes place is a question of electrode kinetics, which are determined by a very complex function of surface conditions, electrical behavior, and solution chemistry." The properties of water affecting corrosion rates, according to Montgomery Engineers, include dissolved oxygen, pH, temperature, velocity, chlorine residual, and chloride. Calcium carbonate ($CaCO_3$) receives attention in discussions of corrosion but its important role is a beneficial one – the formation of protective scale on metal surfaces.

The AWWA *Water Quality and Treatment Handbook*[17] notes that dissolved oxygen serves

[12]A summary of several previous studies begins on page 32.

[13]Orange County Water District, Water Quality and Consumer Costs, May 1972.

[14]Black and Veatch, Consulting Engineers, Economic Effects of Mineral Content in Municipal Water Supplies, Washington, D.C.: Office of Saline Water, May 1967, p.3.

[15]California Department of Water Resources, Southern District, Consumer Costs of Water Quality in Domestic Water Use-Lompoc Area, Los Angeles: June 1978, p. 6.

[16]James M. Montgomery, Consulting Engineers, Inc. Water Treatment Principles and Design. New York: John Wiley & Sons, 1986, p. 393.

[17]American Water Works Association, Inc., Water Quality and Treatment, A Handbook of Public Water Supplies, Denver, Colorado: 1971, author, pp. 299, 309-311.

as a major catalyst for corrosion – water high in dissolved minerals is not particularly corrosive if no dissolved oxygen is present. The Handbook recommends increasing the presence of calcium carbonate to form a protective scale in water system pipes. Certainly the studies conducted on water quality damages to consumers indicate the efficacy of $CaCO_3$ in protecting home piping and hot water heaters, etc. Each of the studies that made comparisons found failure rates increasing as home water softening increased. Water softening by ion exchange, which substitutes sodium for calcium in hard water, increases the effectiveness of soaps, and feels softer against the skin, but it also prevents formation of protective scale, increases the sodium content of drinking water, and may affect the taste.

Hardness.

Hardness in water is a term that means the presence of a significant level of calcium and magnesium ions, i.e., dissolved compounds, usually chlorides, carbonates, sulfates, and (if the water is alkaline) bicarbonates. These hardness constituents (Ca and Mg) cause ordinary soaps to precipitate from solution, and may themselves form calcium or magnesium compounds that precipitate and form scale.

Data from water quality analyses from 1973 to the present indicate a very close and consistent relationship between salinity and hardness in Colorado River water. In the TDS range of 675-720 mg/L (approximate to ppm) hardness (in ppm) ranges from 45 percent to 49 percent of the TDS value. In the 300-550 mg/L TDS range, hardness varies from 49 percent to 53 percent of the TDS value.

A study by Battelle Laboratories[18] confirms that scale build-up on water heaters provides benefits in offsetting corrosion, as well as damages. It noted that softened water effectively reduced scale but accelerated corrosion in water heaters. Although the scale buildup over 20 years of use could reduce efficiency by 4.2 percent, minimizing corrosion was of more benefit to appliance life.

On the other hand, a use and care book accompanying a GE washing machine[19] discusses the problem of "limestone" deposits resulting from a combination of hard water and non-phosphate detergent. The booklet recommends using a phosphate detergent, installing a water softener, or using a packaged water softener with phosphate. It also recommends using hotter water, but no vinegar to change pH. Needless to say, consumers get more concerned about limestone buildup than about the formation of protective scale.

Damages.

In essence, most water-related household damages occur from corrosion – a complex kinetic occurrence that may or may not be related to TDS – or from scale formation which is directly related to hardness. Water from the Colorado River is generally hard to very hard, and its hardness is directly proportional to the TDS level of the water. Scale and hardness of home water appear to be the factors that most concern the average consumer. Corrosion, on the other hand, can cause the more severe economic losses.

Responses to water hardness include such measures as water softening with a resulting purchase of bottled water, purchase of additional laundry additives, or tap filters. The response to corrosion is likely to be premature replacement of plumbing systems and various water-using appliances or parts.

Part of the response on the part of consumers is a direct result of sales pressure. Manufacturers and purveyors of home water treatment systems and bottled water advertise heavily. These factors, combined with the recent increase of attention to the safety of water in terms of toxic waste and other (than salinity) contaminants, have led to an increase in home water treatment systems and in the sale of bottled water.

Bottled water is a particularly interesting case of consumer costs. A number of the studies

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[18] Battelle Columbus Laboratories, The Effect of Water Quality on Residential Water Heater Life-Cycle Efficiency, Third Annual Report (September 1984 - August 1985), Chicago: Gas Research Institute, 1985.

[19] Excerpt of GE Use and Care Pamphlet on Washers, from Air-Conditioning and Refrigeration Institute, 1501 Wilson Blvd., Arlington, Virginia.

on consumer costs related to water quality found a relationship between bottled water purchases and water quality, either hardness or TDS. In fact, in studies that went a step further, the purchase of bottled water was shown to increase proportionally to the use of home water softeners, which also increases with increasing TDS in the water supply. There has been very little publicly available research into why a consumer purchases bottled water, but there is evidence that the taste of softened water may play a role in this relationship.

The International Bottled Water Association provides market research for its members, but the smallest available disaggregation is to a state level (all of California, for example), and most of its information is on a regional (multi-state) basis. California is the biggest market for all types of bottled water in this country. There has been speculation that the life style, awareness of trends, overall wealth of the consumer, etc., plays a role in this. Purchase of bottled water can be classified as a voluntary cost except in those rare instances where a no sodium diet is prescribed or when temporary pollution of a water source occurs.

Only one survey exists that specifically asked consumers in California why they purchase bottled water. That survey, conducted by *The Los Angeles Times* in September 1986, asked registered California voters four questions about drinking water. The survey results were disaggregated to Los Angeles County, Orange County, and the rest of Southern California without Kern County.

The four questions, asked at the end of a long questionnaire, were:

a. Is your usual source of drinking water at home tap water or bottled water? (If tap) Do you have a water filtration device, or not?

b. What is the main reason you don't use bottled water or a filtration device at home: is it because you think your tap water is safe, or is it because bottled water or a filtration device costs too much, or is it because you are satisfied with the taste of tap water, or what?

c. What is the main reason you use filtered/ bottled water at home: is it because it tastes better than tap water, or is it because it's safer than tap water?

d. Just how safe is the water you drink at home? In your opinion, is it perfectly pure at all times, or healthy enough and safe to drink, or do you think it may sometimes be unsafe to drink or toxic?

Over half the respondents in Los Angeles County drink unfiltered tap water, but 48 percent use a filter or bottled water. The same is true for Orange County. Slightly fewer (44 percent) respondents in the rest of Southern California use a filter or buy bottled water. A plurality of those who drink tap water (about 35 percent) do so because they are satisfied with its taste, about 25 percent because they consider it safe, and 25 percent because of its lower cost, and the rest have "other" reasons. More than 60 percent of the respondents felt that the tap water was safe or pure, although one quarter felt that it was unsafe, and the remainder were not sure.

Of particular interest to this study, the reasons for drinking bottled water or using a home filter system were fairly well divided among the three responses in Orange County and the rest of Southern California. Only in Los Angeles County was better taste a stronger motivation than concern for the safety of water. The results for question c for the three divisions are shown in table 6.

Distorted claims that public water supplies are unsafe have been made by some sellers of water softening and purification devices and some bottled water purveyors. To counter these unethical tactics, California in 1986 passed two laws. One requires the State Department of

Table 6. – Reasons for drinking bottled water or for using a home filter system in parts of California

	L.A.	Orange	Rest of So. CA
Taste	45%	35%	37%
Taste & safety	34%	27%	27%
Safety	20%	38%	34%

C—109884

C-109884

Health Services to set standard performance levels for water treatment systems and requires that systems be certified before sale. The other law makes illegal the practice of making false statements about the quality of tap water or to overstate the effectiveness of treatment systems offered for sale or rental.[20]

Articles, such as "Should Tap Water Be For Drinking," in the September 1986 *California Magazine* have focussed concern on toxic contamination of drinking water while recognizing that many consumers seem to prefer the taste of bottled water. A September 8, 1986, article in the *Riverside Press-Enterprise* is headlined "Bottled Water-Sales Soaring With Contamination Scares." The article notes that while California's bottled water purchases remain high, consumers elsewhere in the country are buying more bottled water as they begin to fear their tap water is contaminated. Still, it is clear that taste, or perception of better taste, plays a role in the consumption of bottled water. It is less clear that the taste perception is related to salinity since bottled water sales are among the highest in the country in Los Angeles County which receives very little Colorado River water and is generally supplied with low TDS water. Orange County and the rest of Southern California are much more widely supplied with Colorado River water and more saline groundwater, yet taste is a significantly lower factor in bottled water purchases according to the survey's results.

Costs of bottled water can be linked to salinity damages insofar as salinity is proportional to hardness, which causes increases in home water softening that affects taste, or when salinity is itself so high as to cause noticeable taste effects. Usually, that level cannot be determined without reference to a more complete range of water constituents. However, the proportional TDS/hardness relationship found in Colorado River water does not hold in some areas served by local water supplies. Water hardness, which causes more home water softening, changes "the content and taste of water unfavorably and thus contribute[s] to wider use of bottled water."[21]

Types of Economic Damages to Households

A number of previous studies have investigated the relationship between water quality and consumer costs. As discussed above, there may not be any direct relationship between a single water constituent and damage to a household item. Even so, most of these studies have singled out TDS or hardness as water constituents that are known to cause damage and also are usually identified in the samples of study area water quality.

Previous studies.
In one of the earlier (1972) studies, Metcalf and Eddy's *The Economic Value of Water Quality*, the principal parameters of water quality were found to be TDS, hardness and chloride ion concentration. TDS was found to affect bottled water purchases but not purchases of other bottled beverages. Soap and detergent use was correlated to hardness, and high chloride increased corrosivity. Damage to clothing, landscaping, and plumbing repairs in the home did not correlate to water quality.[22] On the other hand, the 1967 Black and Veatch report, *Economic Effects of Mineral Content in Municipal Water Supplies*, concluded that mineralized water did reduce the useful life of fabrics and various home appliances and fixtures, and increased the use of soaps and detergents. This report does caution that the specific mix of minerals a water supply must be considered, not simply the presence of minerals.[23]

As is true of many of the studies, the Orange County Water District's 1972 *Water Quality and Consumer Costs* reviewed the literature. They looked at DeBoer, et al., (1961) on use of detergents; Leeds, Hill, and Jewett,

[20]Metropolitan Water District of Southern California, Focus, 6 (1986), p. 3.

[21]California Department of Water Resources, Southern District. Consumer Costs of Water Quality in Domestic Water Use-Lompoc Area. Los Angeles: author, June 1978.

[22]Metcalf and Eddy, Engineers, The Economic Value of Water Quality, Washington, D.C.: Office of Saline Water, January 1972, pp. 17-18.

[23]Black and Veatch, Economic Effects, pp. 3-4.

C-109885

Inc. for the Santa Ana Watershed Planning Agency (1970) which was in turn derivative of earlier studies; Patterson (1968) on plumbing and appliances; and, of course, Black and Veatch and Metcalf and Eddy. The caveats presented in these reports were not emphasized in the Orange County discussion; instead, the methods of data collection were examined, and only the Metcalf and Eddy study methods were found satisfactory. To update the "primary data" of that report, Orange County designed a personal interview questionnaire which was administered to 1100 respondents in a modified and stratified random sample.

Despite the fact that the average house age was only 11 years and the average time of residence six years, Orange County concluded that significant economic damages could be related to corrosiveness and hardness in water. All of the survey data was related to TDS or to hardness. Reasons for using bottled water were not correlated to the percentage using home water softeners, nor to respondent age, although those two factors appear to be critical variables in the survey data.

The Metropolitan Water District of Southern California responded to the Orange County Water District report in May of 1972, disputing the approach that showed a linear relationship of TDS and water quality damages. MWD did not dispute the fact that TDS caused damages; rather, the report disputed the direct linking of TDS or hardness to all types of damage.

It was at this point in the literature that d'Arge and Eubanks prepared their section for *Salinity Management Options for the Colorado River*. Their review included Black and Veatch, Metcalf and Eddy, Orange County, and Tihansky's article.[24] Their analysis found the first three references acceptable but without any reference to the caveats stated by Black and Veatch or Metcalf and Eddy about attribution of damages to salinity. Instead they were cited as support for a finding of direct damage linkage.

Tihansky, on the other hand, was criticized specifically as justification for the survey designed by d'Arge and Eubanks. Tihansky was faulted for: his lack of consumer knowledge of expected life or frequency of repair for household items; other variables such as income or age of housing which the authors feel need to be addressed; and the fact that Tihansky does not deal with variations in water quality over time (but d'Arge and Eubanks likewise do not mention variations in water quality constituents except to select survey areas with constituents as similar as possible – although similarities were not defined).

The resulting d'Arge and Eubanks survey involved 87 plumbing contractors and sales and repair personnel who were interviewed in person or by mail and who served as the basis for estimating household economic damages caused by salinity in their study.

In another 1978 study, *Consumer Costs of Water Quality in Domestic Water Use, Lompoc Area* by the Southern District of the California Department of Water Resources, TDS and hardness were again related to household damage. The difference between this study and that by d'Arge and Eubanks is vast. A survey was mailed to residents of the four area communities, to bottled water distributors, plumbing contractors, water softener services and appliance centers. A 51.3 percent return rate was achieved. TDS and total hardness were "used to develop relationships between water quality and costs [because] . . . Data for TDS and TH concentrations were available for at least 10 years. Historic data for other significant quality parameters, such as [dissolved oxygen, carbon dioxide, and Langelier (or Saturation) Index], were not available."[25] Nevertheless, the introductory material to the report contained several pages of discussion and caveats against the presumption of a linear relationship of damages to TDS and even, to some extent, to hardness.

[24]Dennis P. Tihansky, "Damage Assessment of Household Water Quality," Journal of the Environmental Engineering Division, American Society of Civil Engineers, Vol. 100, No. EE-4, August, 1974, pp. 905-917.

[25]California Water Resources, Consumer Costs, p. 12.

Coe's 1982 dissertation on *Water Quality Related Consumer Costs in Domestic Water Use*[26] followed the same general format as the - California DWR study. He also discussed other water quality parameters that can increase consumer costs, but linked his data to that of available historic parameters — TDS and total hardness (TH).

Assignment of TDS share of damages. This brief review of the literature illustrates a critical point. That is, in developing economic damages that result from poor water quality, the constituents about which most information is available are TDS and hardness. Therefore, those two related constituents (which not always are related linearly) are the ones most often used in discussions and findings of damage. Yet they are not always solely responsible for increased consumer costs, because of the influence of other damaging factors. Therefore damage estimates related to TDS or hardness must be considered as approximations rather than as precise measures. The 1972 MWD[27] response to the Orange County report has attempted to qualify the calculated damages attributed to salinity by judgmentally adjusting them to reflect other factors. See table 7.

MWD's response to the Orange County report makes valid points throughout. First, TDS or hardness cannot be claimed as the sole causes of water-related appliance problems. Toilet flushing mechanisms, for example, are subject to enormous daily mechanical wear and tear depending upon family size and number of toilets.

Second, either salinity and hardness or advertising can influence consumer actions such

Table 7. — Orange County Water Quality Cost Study
Answered by Metropolitan Water District

	Orange County	MWD Response	Percentage MWD attributes to TDS
Hardness factors			
Home water softeners (% of homes)	31%	19%	19%
Total annual cost of softening	$6,138,000*	$3,762,000	39
Increased cleaning supplies	6,210,000*	0 — at the time MWD had a central softening plant	
TDS & TH factors combined			
Bottled water total annual cost	2,160,000	1,404,000	13
Water Heater total annual cost	1,290,000	390,000	50
Water Piping per home**	14	6	43
Faucets per home**	7	4	50
Toilet Flushing mechanisms per home**	1	1	70
Garbage Disposals per home**	4	0	0
Clothes and Dishwashers per home**	18	6	33
Water damage per home**	16	7	42
Pool Cleaning per home**	1	1	?

*Total costs for estimated 150,000 Orange County homes
**Annual cost differential

[26] Jack Jacobi Coe, Water Quality Related Consumer Costs in Domestic Water Use, unpublished doctoral dissertation, University of Southern California, 1982.

[27] Metropolitan Water District of Southern California, "Review of Report of Orange County Water District on Water Quality and Consumer Cost," May 2, 1973.

as purchase of home water softening or purchases of bottled water, so that distinguishing a salinity damage from a consumer preference can be difficult. MWD accepted that consumer damages resulted from salinity in household water supplies. The response to the Orange County study was an attempt to distinguish damages that could occur with the use of local or state water from damages that could occur with the use of Colorado River water. For example, MWD pointed out that the plus or minus 600 mg/L TDS water used for damage calculations by Orange County should have been recognized as an increment over the approximate range of state water at the time (about 150-200 mg/L TDS).

Various Types of Household Damages.

While it is clear that water-quality related damages cannot be solely attributed to TDS or to hardness, there are many types of household damages that can be attributed, at least in part, to high TDS levels. Certain types of TDS-related damages can be found in automobile radiators, in water heaters, in home water and wastewater piping, and in the purchase of alternative water supplies. Some of the earlier studies also described salinity damages to garbage disposals, dish and clothes washers, toilet flushing mechanisms, and faucets. However, stain or corrosion damage to basins, tubs, and sinks does not appear to be primarily caused by salinity or hardness, but is more likely to result from iron compounds or from softening that removes protective scale.

The studies reviewed were not always consistent in finding correlation between damage to a particular item and salinity. However, these studies represent the best data available and a list of the findings from all that were reviewed is included as table 8. Since Colorado River water quality shows a consistent relationship between TDS and hardness, it can also be assumed that such damage percentages for TDS can be assigned to hardness.

Reviewing the findings for the various items listed in these tables reveals significant discrepancies in findings on useful life. However, they generally show that useful life decreases as salinity increases, thus resulting in an economic damage.

Table 8. – Findings of TDS Link to Household Damage

Type of Damage: Buying bottled water or home filters** (percentage of entire study)*

Source	TDS	Percentage
Coe	228	05.7*
	526	46.2*
	712	35.1*
	749	18.7*
Calif. Dept. of Water Resources	547	11.0*
	700	30.0*
	838	24.0*
	857	48.0*
Orange Co.	199	13.0*
MWD	746	26.0*
LA Times	222	36.0*
	720	35.0*
	600	30.0*
LA Times	222	12.0**
	720	12.0**
	600	14.0**

Type of Damage: Life Span of Water Pipes in Years

Source	TDS	Galvanized	Copper	Unspecified
Coe	228			20.6
	526			15.4
	712			15.0
	749			8.9
Tihansky	200			32.9
	400			26.6
	600			22.2
	800			19.1
	1000			17.0
	1200			15.5
d'Arge & Eubanks	210	17.28	44.08	
	728	11.25	47.50	
Calif.	547	7.1	10.0	
	700	10.0	10.0	
	838	14.1	14.9	
	857	0.0	8.1	
Patterson & Banker	118	25.0		
	250	35.0		
	606-690	25.0		
	748	13.0		
	818	10.0		
	843	15.0		
	1000	10.0		
Orange Co.	200	35.0		
	750	25.0		

Type of Damage: Life span of Garbage Grinders in years

Source	TDS	Years
Tihansky	200	8.9
Patterson	118	9.0
Banker	400	8.1
	250	8.0
	600	7.4
	748-843	5.0
	800	6.9
	1000	6.5
d'Arge & Eubanks	210	8.47
	728	6.86
Orange Co.	200	8.0
	750	6.0
MWD	No TDS effect	

Type of Damage: Life Span of Clothes and Dish Washers in Years

Source	TDS	Years
Coe	228	12.0
	526	9.9
	712	10.2
	749	12.6
Patterson & Banker	250	10.0
	818	7.0
	843	10.0
	1750	7.0
d'Arge & Eubanks	210	8.5
	728	7.38
Orange Co.	200	10.0
	750	7.0
Tihansky	200	10.1
	400	9.4
	600	8.7
	800	8.2
	1000	7.7
	1200	7.3
California	547	8.9
	700	7.7
	838	9.1
	857	6.8

Type of Damage: Life Span of Toilet Flushing Mechanism in Years,

Source	TDS	Years
Coe	228	12.0
	526	10.1
	712	10.2
	749	11.7
Patterson & Banker	118	10.0
	250	10.0
	606	4.0
	690	5.0
	748	2.0
	818	5.0
	843	7.0
	1750	3.0
Orange Co	200	10.0
	750	7.0
Tihansky	200	10.1
	400	8.0
	600	6.5
	800	5.3
	1000	4.5
	1200	3.8
d'Arge & Eubanks	210	7.68
	728	6.63
California	547	6.8
	700	8.1
	838	8.0
	857	6.0

Type of Damage: Life Span of Hot Water Heaters in Years

Source	TDS	Years
Coe	228	12.4
	526	10.6
	712	14.1
	749	8.7
Patterson & Banker	118	10.0
	250	13.0
	606	6.0
	748	9.0
	818	8.0
	843	10.0
	1000	5.0
d'Arge & Eubanks	210	8.74
	728	5.22
Orange Co.	<600	8.7
	>600	7.7

Type of Damage: Life Span of Hot Water Heaters in Years, cont

Source	TDS	
Tihansky	200	13.3
	400	11.3
	600	9.7
	800	8.6
	1000	7.7
	1200	7.1
South Australia	40	15.0
	380	8.9
	1060	5.0
California	547	7.2
	700	8.2
	838	6.4
	857	8.7
MWD	199	10.0
	746	7.0

Type of Damage: Life Span of Faucets in Years

Source	TDS	Years
Coe	228	16.0
	526	10.4
	712	11.5
	749	10.7
Patterson & Banker	118	8.0
	606	8.0
	690	13.0
	748	6.0
	818	7.0
	843	6.0
	1000	7.0
d'Arge & Eubanks	210	10.4
	728	6.0
Tihansky	200	10.9
	400	10.4
	600	9.8
	800	9.3
	1000	8.7
	1200	8.1
California	547	7.7
	700	7.7
	838	8.1
	857	6.4
Orange Co.	200	11.0
	750	8.0
MWD	199	22.0
	746	16.0

Estimation of Salinity Damages to Households

The determination of the costs to households, caused by salinity, is in large part based on results of several earlier studies. Those reviewed were: DeBoer (1961); Black and Veatch (1967); Patterson and Banker (1968); Leeds, Hill and Jewett (1970); Metcalf and Eddy (1972); Orange County Water District (1972); MWD (1972); Tihansky (1974); d'Arge and Eubanks (1978); California DWR (1978); South Australia (1982); Coe (1982) and Tinney (1986). The authors of the current report obtained supplementary data on the effects of salinity's role in corrosion of household piping from municipal plumbing inspectors in numerous metropolitan areas in the Lower Basin, and developed information from primary sources on salinity damages to automotive cooling systems.

The authors interviewed experienced plumbing inspectors with county and municipal agencies, as well as building renovators, in the Las Vegas, Tucson, Phoenix, and Southern California areas to determine changes in water and wastewater piping materials and to determine the useful life of pipe materials in their jurisdiction. The inspectors, who inspect all new and replacement installations of pipe, generally state that copper plumbing rarely presents problems and that those that occur can be attributed to causes other than corrosion, such as electrolysis or alkali soils. They stated that plastic pipe hasn't been around long enough to cause problems, and that PVC pipe will probably last forever.

The following household items were determined to have a useful life that decreased as TDS increased, although as discussed elsewhere in this report the decrease in useful life by corrosion or scale is a complex process that is influenced by particular constituents in water and by temperature, velocity, etc., rather than by salinity (TDS) concentration alone:

- Household water pipes (galvanized iron; not copper or CPVC)
- Household wastewater pipes (cast iron; not ABS, PVC or polybutylene)
- Water heaters
- Faucets
- Garbage grinders ("disposals")
- Toilet flushing mechanisms

Clothes washers
Dishwashers

Certain other types of household appliances or facilities have been mentioned in one or more of the earlier studies as having useful life reduced by salinity. These are: bath tubs, laundry tubs, sinks, and electric kettles. They have not been included here because of limited data or because in the authors' judgment there is insufficient evidence that salinity can damage their constituent materials.

Opinions on this point may differ. Those who may wish to expand the list of household items subject to salinity damages are referred to the following data on useful life (expressed in ranges of years) which are not included in the computer program developed in this study:

Toilet: 9.6 - 20.0 years (Coe)
Bath Tub: 9.5 - 22.7 years (Coe)
Basin: 12.6 - 18.4 years (Coe)
Sink: 12.2 - 19.4 years (Coe)
Laundry Tub: 10.0 - 17.7 years (Coe)
Electric kettle: 5.0 years (South Australia)
Copper water pipe: 43.78 - 43.82 years (d'Arge & Eubanks)
Copper wastewater pipe: 48.33 - 60.00 years (d'Arge & Eubanks)
Plastic water pipe: 48.33 - 60.00 years (d'Arge & Eubanks)
Plastic wastewater pipe: 42.50 - 53.00 years (d'Arge & Eubanks)

Regressions on Useful Life of Household Appliances

Data on useful life of several water-using household appliances under varying salinity levels were obtained from earlier studies. These appliances were: household water pipes, household wastewater pipes, water heaters, faucets, garbage grinders, toilet flushing mechanisms, clothes washers, and dishwashers. Data on washing machines did not distinguish between clothes washers and dishwashers in terms of useful life, so the data were used for both. Data from some studies, when plotted, were significantly different from the majority of studies. Therefore a few data sets were selectively omitted on a judgmental basis. Where discrepancies were found, greater emphasis was given to data developed from observation, rather than from interviews with household members. Where TDS/useful life relationships were given a mathematical formula, as was true in Tihansky's work, values were calculated through the range of 200-1200 mg/L.

Data on useful life of household water and wastewater pipes were based on galvanized iron, copper, or on unspecified materials. Perhaps because of this, the data were erratic. It was decided, for sake of consistency, to use data from a single study —that of Dennis Tihansky[28] — for both types of pipes. Tihansky's data were obtained from a variety of sources and were reduced to the following form of formulas, which have been modified in notation so that A & B = constants, ^{m} = power (^{1}, ^{2}, or ^{3}), y = useful life in years, and t = tds in mg/L:

$$y = A \pm Bt^m$$

The special computer program, described in chapter 3 to calculate regression formulas for crop yield, also was used to calculate regression formulas for useful life of water-using household appliances, and to plot regression curves. Three regression formulas and curves were calculated and plotted for each of the remaining household items, using polynomials to the first, second, and third power. The regression which gave the best, i.e., lowest, Goodness of Fit Criterion was selected for use in this study. The formulas are as follows, with coefficients rounded:

Water heaters: $y = 14.63 - 0.013t + 0.689 (10^{-5})t^2 - 0.11 (10^{-8})t^3$

Faucets: $y = 11.55 - 3.05(10^{-3})t$

Garbage grinders: $y = 9.23 - 3.87(10^{-3})t + 1.13(10^{-6})t^2$

Toilet flushing mechanisms: $y = 11.48 - 6.29(10^{-3})t$

[28] Tihansky, "Damage Assessment of Household Water Quality," p. 908.

Clothes washers: $y = 14.42 - 0.0114t + 0.46(10^{-5})t^2$

Dishwashers: $y = 14.42 - 0.0114t + 0.46(10^{-5})t^2$

An example of a regression curve is shown in Figure 7.

While two of the regression curves are linear, the other four curves have a curvilinear shape, which most often took the shape of a Gompertz or logarithmic curve, in which the useful life decreases at a decreasing rate as TDS increases, and approaches an asymptote representing minimum useful life.

Other Factors Affecting Estimates of Salinity Damages to Households

Several complicating factors have been considered in developing the methodology to calculate future household damages from salinity. Changes in household characteristics over time, such as a declining number of persons per household and an increasing number of automatic dishwashers per household, must be reflected. Changes in piping materials over time, as permitted by periodic changes in the Uniform Plumbing Code, also must be reflected. Still another factor to be considered is that some of the "household" salinity damages occur outside households, e.g., in commercial buildings that have facilities and appliances similar to those in residential buildings. Examples are: restaurant garbage grinders and dishwashers; hotel and office building bathrooms and water heaters. Methods for considering these complicating factors in the computer program are discussed later in this chapter of the report.

The method used to compute annual salinity damages involves identifying the service lives of household items used under various TDS concentrations, then calculating the number of such items in use in a given year in a given metropolitan area. This equals the number of items per household times the number of

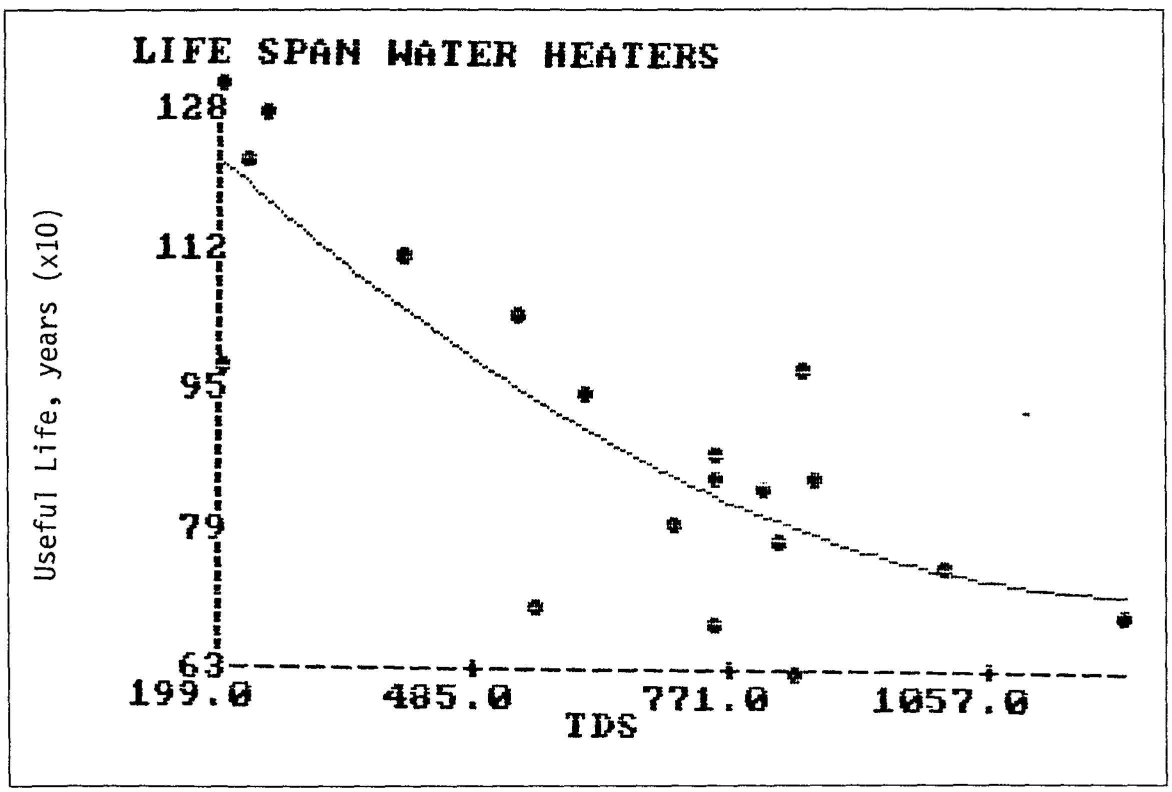

Figure 7. — Life span of water heaters vs salinity level

C-109892

households, multiplied by an extrapolation factor to expand household items to include similar items in commercial buildings.[29] The replacement cost of the item is determined (in 1986 $), then is divided by the number of years of useful life at the given year's forecasted TDS level, to obtain the annual salinity damages per item. Since even at a very low salinity level, such as 200 mg/L, there will be a limit to useful life, the damages due to salinity at a higher salinity concentration will be the difference in cost between two salinity levels, the forecasted level and the selected baseline level(s).

Household Damage Categories Unrelated to Useful Life of Appliances

Not all household salinity damages are functions of useful life. Others are functions of annual cost per household for certain expenditures that increase with higher salinity concentrations. These are:

- Bottled water purchases
- Home water treatment systems (e.g., home water softeners or "under-sink" ion exchange systems or home RO systems)
- Soaps and detergents
- Clothes replacement (i.e., from textile wear caused by water hardness)

All four of these categories are subject to caveats. Bottled water purchases are stimulated in part by advertising, in part by unjustified fear of pollution in public water supplies, and in part by taste. Income level and purchasing power also correlate with bottled water purchases. The same factors influence expenditures on home water treatment systems, with the added factor that home water softening causes some deterioration of water taste (and increases corrosivity) which in turn causes an increase in bottled water purchases.

Water hardness causes increases in the amount of soap and detergent used in a household, and may reduce the useful life of textiles. Income level and personal preference are probably primary factors in the premature replacement of clothing because of fashion considerations rather than wear. Nevertheless, hardness and salinity, particularly in the Colorado River, are closely related so that an increase in one usually accompanies an increase in the other. The authors have determined from secondary sources what the annual expenditures per household are for these four categories, and what percentage of households make such expenditures, at various TDS levels. All costs have been indexed to 1986 dollars. The damages, as before, are the difference in annual expenditures per household at two levels of salinity (the forecasted level and the selected baseline level(s), multiplied by the number of households making those expenditures, multiplied by an extrapolation factor to account for similar expenditures made outside households, e.g., water treatment systems in commercial buildings, bottled water purchases by hotels and restaurants, extra use of soaps and detergents by commercial laundries, and extra damages to hospital and hotel linens. (Damages from commercially laundered textiles, in particular, also can result from the very hot water and strong detergents used).

Salinity Damages to Automotive Cooling Systems

A final category of household salinity damage is that of damage to automotive cooling systems, particularly radiators, from saline water

[29]The extrapolation factor calculated for use in the computer program is 53.1 percent, and is based on the relationship between the volumes of water distributed to commercial customers and to residential customers of the City of San Diego Water Utilities, as reported in its Fiscal 1986 Annual Financial Report, p. 28. These volumes were 2,784 million cubic feet (commercial) and 5,243 million cubic feet (residential). Water distributed to industrial customers was ignored, because the proportion of industrial water used in bathrooms, etc., is assumed to be negligible. The San Diego data did not indicate if, or where, water sales to public authorities are reported. A similar calculation of commercial and residential water use in Denver from p. 64 of the Denver Water Department's 1985 Annual Report, indicated an extrapolation factor of 51.0 percent. The Denver calculations did not include water used by public authorities (e.g., schools, government offices, street washing, etc.) which represents 15.9 percent of residential use, and therefore they understate non-residential damages.

added to radiator coolant. Although none of the prior studies listed above have included this type of damage, the authors' primary research has determined that it is very significant in terms of economic costs in the southwestern U.S.

Data on the effects of saline water on automotive cooling systems have been obtained from Chrysler Motors, General Motors Research Laboratories, and the Chairman of the ASTM Committee D-15 on Engine Coolants, Mr. Roy E. Beal, President of Amalgamated Technologies, Inc., Scottsdale, Arizona.

Mr. D. W. Doran, Manager of Engineering Standards and Product Information for Chrysler Motors, wrote:[30]

> It is the opinion of our Cooling Systems Engineering Department that a moderate level of salts in a properly maintained Chrysler cooling system will not appreciably contribute to corrosion of the metal components. This statement must be qualified by a few details:
>
> 1. Moderate levels means a level of chloride of 300 ppm. Above this level the inhibitors in anti-freeze are unable to counteract the corrosive effect on the metal components. Aluminum is particularly susceptible to the crevice and pitting corrosion this will cause. Chrysler uses copper/brass radiators in about 85% of its vehicles, so we are better off than other manufacturers. However, the other aluminum components, such as the water pump, the thermostat housing, and the intake manifold, all could be adversely affected. This could cause an increase in water pump failure along with radiator plugging.
>
> 2. "Properly maintained" means that the customer follows the procedure recommended in the owner's manual. There is reliable data available which shows that this is the exception, not the rule. According to SAE Technical Paper #831821, *A One Thousand Car Assessment of the U.S. Car Population Cooling Systems*, 36.4% of the vehicles surveyed had less than the recommended 45% antifreeze concentration. The situation is even worse in the West where 56% of the population is under the recommended concentration. About 13% were running with less than 5%. These low concentrations will not sufficiently protect the metal components from corrosion, particularly if they contain high chloride levels.
>
> . . . If the 500 - 1000 mg/L of total dissolved solids quoted in your letter are all chloride ions, then this would be considered an excessive level. Customers should be advised not to use this water in their cooling systems.
>
> We feel that the public should be made more aware of the adverse effects of high salinity water on cooling systems and the importance of proper anti-freeze maintenance. In this way the economic impact of this problem could be minimized. We have recommended that the subject be addressed at the next meeting of the ASTM Committee D-15 on engine coolants . . .

Subsequently, Mr. G. G. Levy, Supervisor of Materials Protection and Joining – Corrosion, Chrysler Motors, reported that he had brought the subject of salinity to ASTM Committee D-15 whose members "represent the Antifreeze Manufacturers, Chemical Companies, U.S. Government and State Agencies, Radiator Manufacturers, and the Automotive Companies.

The following are the comments of the committee membership:[31]

- A *properly* maintained cooling system can tolerate 100 ppm (100 mg/L) of salinity.
- A *properly* maintained cooling system *may* be able to tolerate 300 ppm of chlorides but the corrosion protection of the coolant will be greatly reduced.
- No data exists on the corrosivity of higher salinity waters in cooling systems.
- While the increase of salinity to 500 ppm and above would be catastrophic to aluminum radiators and other aluminum components it would also cause increased corrosion failures of copper brass radiators.

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[30] Personal Communication, October 10, 1986.

[31] Personal communication, October 17, 1986.

- No one volunteered, at this time, to run corrosion tests on Engine Coolants with these higher levels of salinity.

Mr. Roy E. Beal, Chairman of the ASTM Committee D-15, commented:[32]

> As noted by Chrysler, the most aggressive ion is chloride in overall corrosion, particularly with solder and aluminum. Oxidizing ions such as nitrates cause problems with copper alloys under stress. High total solids cause reduction in the overall life of pumps and leads to tube blockage in radiators and consequent overheating type failure.
>
> Generally, more salt content will reduce the effectiveness of the balanced inhibitor package in the coolant, so increased damage can be expected. The main difficulty is that no knowledge is available, at least publicly, on just how much can be tolerated. We would slightly disagree with Chrysler in that we know 100 ppm [chloride] or above is too much and causes premature cooling system failure.
>
> Increased aggressiveness of a water by salt content does not cause a linear increase in corrosion, it would tend to accelerate it if not counteracted. Your letter raised two questions, that are: what does the effect of high salt water level have now, and what will the future levels of high salt level do. We do not know, but can reasonably expect at least a 10% increase in overheating or corrosion failure.

Considerable assistance in scoping the economic consequences of salinity damages to cooling systems was provided by Mr. Charles W. Mackenzie, Editor and Publisher of *Radiator Reporter and Pricing Guide*, an authoritative trade journal. Mr. Mackenzie wrote:[33]

> In the matter of the effect of Colorado River water on radiators, we know that there are twice as many radiator repair shops in the southwest per 100,000 vehicles as in, for instance, Minnesota, presumably due to more available work. However the Southwest also has higher temperatures, it is heat plus bad water that makes business for radiator repair shops, assuming equal owner neglect in all areas.
>
> In the matter of costs to the consumer, I enclose a copy of our long-continuing pricing studies. Retail is the price to the car owner, wholesale is the price to a car dealer, garage, or gas station. A clean and repair is boiling out in a caustic, or cleaning in an ultrasonic tank, and the repair of all leaks as determined by tests, plus renewal, repair, and repainting all around. A recore is the replacement of the tube fin nest, salvaging tanks, oil coolers, side pieces, and other parts.
>
> Sixty-two percent of all radiator shop job tickets are for the less expensive clean and repair operation. 24% are recores, the balance complete replacements. However, these figures apply only to the conventional copper/brass radiators.
>
> Presently, more than half of car production uses an aluminum, rather than copper/brass core. For reasons too broad to get into at this time the aluminum core is almost never repairable and the cheaper repair will simply not apply. Chlorides in water hurry this aluminum corrosion process.

Precise data are not available on the volume or frequency of radiator repair in the southwestern U.S. compared with less saline areas. Using the available data, plus inference, the assumption is made that 70 percent of automobiles (and trucks) in areas having salinity of 300 to 500 mg/L will face some radiator repair or replacement during the automobile's life, compared with 35 percent of automobiles in areas where salinity is 200 mg/L TDS or less. The percentage of vehicles requiring radiator service during their lifetime is assumed to rise to 90 percent at salinity levels of 800 mg/L or higher. *Radiator Reporter* notes that more than 70 percent of all radiator jobs occur in the fourth to ninth year of the car's life. Thus, the authors assume a frequency of $(4 + 9) / 2 = 6.5$ years for radiator repair or replacement at TDS levels of 200-300 mg/L. The frequency is assumed to increase at

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32Personal communication, November 7, 1986.

33Personal communication, October 3, 1986.

higher salinity levels, to 4.0 years at 500 mg/L and to 2.0 years at 800 mg/L TDS and higher. Thus in a 300 mg/L TDS area, for every 100 automobiles, 10.8 would need radiator repair or replacement each year. That is, (100 x 70%) / 6.5 = 10.8. In a low salinity area (200 mg/L or less), 5.4 percent of automobiles would need radiator service annually.

The average cost of radiator service can be established more closely. Using data from *Radiator Reporter and Pricing Guide*, plus local data on the cost of radiator replacement, the average cost is calculated as $99.20 for copper and brass radiators.

62% clean and repair @ $35.00 = $21.70
24% recores @ $145.00 = $34.80
14% replacement @ $305.00 = $42.70
Weighted Average = $99.20

For aluminum radiators, clean and repair is not effective, so the average cost is calculated as $204.20.

63% recores @ $145.00 = $ 91.35
37% replacement @ $305.00 = $112.85
Weighted average = $204.20

As more than half of the automobiles use aluminum radiators, a weighted average repair/replacement cost of $162.20 (1986 $) is used.

(60% x 204.20) + (40% x 99.20) = $162.20

Automobile cooling systems are added to the list of items for which expenditures increase with higher salinity concentrations. The average number of automobiles and trucks per household in each southwestern metropolitan area (1.52) has been determined from Census data, and an extrapolation factor (1.29, also calculated from Census data) has been used to account for commercial and industrial vehicles. No estimate is made for salinity damages to water pumps and other cooling system components because of lack of data, so the automotive damages are somewhat understated.

Current Average Value of Salinity Damaged Household Items

Since this study covers all of the lower Colorado River Basin, Los Angeles, and San Diego, the average value of household items that may be damaged by salinity is derived from the Fall/Winter 1986 Sears catalogue which is considered to contain representative retail appliance costs over the region. The prices listed represent full (1986 dollars) replacement value for mid-range items and includes freight and local taxes. Average replacement costs for household water pipes (replaced by copper) and household wastewater pipes (replaced with plastic) have been estimated for a typical southwestern home by a plumbing contractor, and include labor. Costs of water heater replacement have been estimated at 75 percent including installation labor, 25 percent without labor. Most of the other items can be self-installed so, for conservatism, no labor costs are included. Other commercial installation and labor costs also are omitted, since the proportion of hired installation is not known. This results in an understatement of actual damages.

- Gas Water Heaters - 5 year warranty 30-gallon: $161.25; 40-gallon: $184.38; 50-gallon: $232.33; 40-gallon installed (from plumbing firm estimate): $307.00
- Electric Water Heaters - 5 year warranty 30-gallon: $150.79; 40 gallon: $173.01; 52-gallon: $196.92
- Laundry tub - $ 60.05
- Tub faucet - $32.02
- Garbage disposal - 1/2 horsepower: $125.29
- Kitchen faucets: $63.99
- Bathroom faucets: $63.94
- Bathtub faucets: $96.02
- Built-in dishwasher: $416.58
- Clothes washer: $446.34
- Toilet: $96.41

- Toilet flushing mechanism: $3.24
- Ten piece cookware set: $208.23
- Automobile radiator, average of franchised dealer and secondary market costs: $305.00
- Automobile radiator, average repair: $162.20
- Copper water pipe, per foot, 3/4 inch: $0.87; 1/2 inch: $0.78
- Copper wastewater pipe, per foot, 1 1/2 inch: $0.83; 2 inch: $1.11; 3 inch: $2.61
- Plastic water pipe, per foot, 1/2 inch: $0.57; 3/4 inch: $0.64
- Hourly plumbing rates, average $40.00
- Hourly installer rates, average $30.00

Note that almost every item discussed in any study is listed here. Appearance on this replacement value list does not indicate that each item is damaged by salinity – inclusion simply means that the item has been described in at least one study as damaged by water quality.

The California Department of Water Resources study discussed the costs of water softeners in some detail. For owners of water softening units the monthly regeneration costs averaged $3.40 in 1978 ($5.74 in 1986 dollars). The average purchase cost of the unit, in 1978, was $371.00 ($626.00 in 1986 dollars). Many areas in southern California prohibit the use of home regenerative softeners as part of local waste discharge requirements, thus requiring use of rental equipment. The 1986 average monthly rental for a prominent residential water softener in Southern California was $22.00. The same equipment cost $10.71 in 1978. This California DWR study also found that people were three times likelier to purchase bottled water *if* they used a home water softener.

Coe's 1982 study found less of a correlation than the California DWR study did between water softening and bottled water purchase, but more of a correlation with cost of the two services. The 1982 average monthly cost of home regeneration was $4.28 and the average monthly rental of softening units was $13.70.

Forecasts of Future Population and Households by Metropolitan Area

Data on the population now served in whole or part with Colorado River water, and the forecasted future population to be served, have been gathered from sources believed most reliable. These are:

For the MWD service area, including the Counties of Los Angeles, Orange, Riverside, San Bernardino, San Diego, and Ventura, *The Metropolitan Water District of Southern California 1982 Population and Water Demand Study, Report No. 946*, December 1982 [includes projections to 2010]. The 1986 population figures in table 9 are Metropolitan's recent estimates of April 1, 1986, population.

Table 9. – Current and future population of study areas

Municipality/Area	1986 Population		2010 Population	
MWD Service Area:				
Los Angeles Co	7,697,000		8,800,000	
Orange Co	2,154,450		3,070,000	
Riverside Co	595,000		1,000,000	
San Bernardino Co	410,000		670,000	
San Diego Co	2,030,000		3,100,000	
Ventura County*	394,000		740,000	
Pima Co./Tucson	645,038		1,198,508	
Maricopa Co./Phoenix	1,923,000	e	4,052,000	
Clark Co./Las Vegas	572,800	e	993,400	
USBR, All American/ Imperial	120,000	e	120,000	e
USBR, other LC projs.	166,032	e	166,032	e
Colo. River Mainstream	30,100		30,000	e
Total	16,737,420	e	23,939,940	e

* Normally, no Colorado River water is distributed in Ventura County, so the damage estimates in this study do not include Ventura.

These data show the current (1986) and future (2010) population of the study area to be that as shown in table 9 (the authors' interpolations and estimates are marked "e.")

For Phoenix: Maricopa Association of Governments Transportation and Planning Office, *Total Resident Population, Municipal Planning Areas and Districts, Maricopa County, 1980-2015,* adopted October 22, 1986.

For Tucson: *Pima Association of Governments 1985 Population Handbook* [includes projections to 2010].

For Las Vegas Valley: State of Nevada Office of Community Services, *1986 Statistical Abstract* [includes growth forecasts to 2010].

For smaller municipalities and water districts served by the Boulder Canyon Project, All American Canal, Imperial Division, *Reclamation Project Data*, p. 71.

For smaller municipalities and water districts served with irrigation, municipal and industrial water by other Bureau of Reclamation Lower Colorado Region projects, *1985 Summary Statistics, Vol. I, Water, Land and Related Data*, p. 66. [These include Yuma, Gila, Yuma Auxiliary, Roosevelt Water Conservation District, Roosevelt Irrigation District, and Brown Canal in Arizona, and certain urban and suburban areas in California.]

For Colorado River Mainstream towns (Needles, Blythe, Lake Havasu City, and Parker), *Rand McNally Commercial Atlas, 1986.*

These forecasts indicate growth in population of the study area of 43.0 percent from 1986 to 2010. Only a portion of this population obtains M&I water from the Colorado River, because of reliance on other surface and groundwater supplies and blending.

Forecasts of the number of households in each area are calculated by dividing the population by the Number of Persons per Household in the most recent Census of Population and Housing. This is "Population in Housing Units" divided by "Occupied Housing Units." In recent years, the number of persons per household has decreased in the United States through socioeconomic change. However, for purposes of this research, no attempt is made to project future changes in household size.

Estimating Current and Future (1987-2010) Salinity Damages to Households

The computer model used to calculate household (consumer) damages for any year or multi-year period from 1986 to 2010 begins by displaying certain items of data used throughout the calculation: the discount rate used to compute the present value, in 1986 dollars, of damages in future years;[34] the extrapolation factor used to extend the damages computed for

[34] As explained in the program instructions, if a zero discount rate is used, the damage estimate is a future value, not discounted to the present. This is the program's default input data.

The selection of a discount rate for computing the present value of future damages is subject to the user's judgment, depending on the purpose for which the salinity damage estimate is to be used. The U.S. Government annually establishes a discount rate for the formulation and economic evaluation of plans for water and related land resources projects. [U.S. Water Resources Council, Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies, March 10, 1983, p. 5.]This rate of 8.875 percent, which can be substituted in the input data to the computer program, is the appropriate rate for use in federal implementation studies for FY 1987, including studies of federally-sponsored salinity control measures. The rate may change each fiscal year.

However, the true estimate of damages to any individual or group is their actual cost of capital, i.e., the interest they pay on borrowed money, or money invested by stockholders. This rate will be highest for individuals, lower for industrial and commercial borrowers, still lower for the federal government, and lowest for state and local governments. These differentials exist because of differing risks of repayment and because of interest subsidies related to differences in income tax treatment. Although it appears operationally impractical for the user of the computer program to do so, the conceptually correct discount rates to use for determining damages would be: average state and municipal bond yields, for state and local governments; U.S. Treasury Bill rates, for the U.S. Government; average commercial paper rates, for large commercial and industrial borrowers; average bank loan rates to smaller commercial and industrial borrowers; and bank loan or credit card interest rates to households.

residential households to include similar types of damages in commercial buildings; and the average number of persons per household. The user of the model is free to change any of these items of data for damage calculations.

Next, the model invites the user to display and to change, if desired, certain data entered in the model's data bank: the cost (in 1986 dollars) of each of a group of household items; the average number of items per household (originally based on Census of Housing data for each metropolitan area); and the useful life of the household item as determined by the TDS level of the household water supply. The household items are:

Household water pipes (galvanized iron)
Household wastewater pipes (cast iron)
Water heaters
Faucets
Garbage grinders
Toilet flushing mechanisms
Clothes washers
Dishwashers

Over time, socioeconomic changes may affect the average number of such items in a household and technological changes may affect their average cost (in 1986 dollars) and their average life. However, these changes are not expected to occur frequently, or to be dramatically large.

Next, the model invites the user to display and to change, if desired, certain data on other household items entered in the model's input data bank. These are: annual cost, or expenditure, per household (in 1986 dollars); and the percentage of households using the item at a specific TDS level. These household items are:

Bottled water purchases
Home water treatment systems
Soaps and detergents
Clothes replacement
Automotive cooling systems

Some explanation is needed on these computational data items. In the case of bottled water purchases and home water treatment systems, both the annual cost per household and the percentage of households affected can be expected to increase to some degree as TDS increases. That is, as salinity concentrations rise, some households begin to purchase bottled water as a replacement for tap water, and other households buy more bottled water than before, for other uses. Similarly, more households buy home water treatment systems as salinity rises, and those who have such systems pay more for chemicals and service. All households presumably purchase soaps and detergents and have laundry wear or fabrics requiring replacement, and these costs may increase as salinity increases. In the case of automotive cooling systems, the average number of automobiles and trucks per household is a fixed number (from Census data) and the average cost per vehicle for a radiator repair or replacement is relatively fixed. Here, subject to recalculation as prices change and as technology (e.g., ratio of aluminum to copper/brass radiators) changes over time, the major variable is frequency of repair or replacement, expressed as the percentage of households requiring a radiator repair in a given year. This percentage increases as TDS increases.

Therefore the model displays both annual expenditure per household and percentage of households affected, as functions of TDS. Depending on the type of household item, one of these computational factors may not vary with TDS level.

Next, the model invites the user to display and to change, if desired, the population and the TDS level of each metropolitan area served with Colorado River water, by five-year increments, from 1986 to 2010. The baseline TDS level has been preselected by the user when beginning the program's operation.

The computer model displays nine metropolitan areas, plus the total of these areas. These are:

Los Angeles County
Orange County
Riverside County
San Bernardino County
San Diego County
Maricopa County (Phoenix)
Pima County (Tucson)
Clark County (Las Vegas Valley)
Lower Colorado River Communities (which includes portions of Imperial County, other USBR Lower Colorado Projects, and Colorado River Mainstream Towns)
Total of all nine of the above areas

These data are expected to be quite stable, although the values for TDS level can be changed as desired to forecast the effects of proposed salinity control measures, etc.

The model users next can calculate the total household (consumer) damages for a selected metropolitan area (or areas), and the average damages per household. This can be done for a single given year or for a period of years, as desired.

The model next computes these damages separately for each of the eight household items whose useful life varies with TDS level, and for each of the five household items for which the annual household expenditures vary and/or the percentage of households affected vary. The model sums these damages by type, and displays them (as desired by the user) alternatively as tabular data or as a bar graph. If desired, the model will print the tabular data or the bar graph.

In determining the household damages attributable to salinity levels of the Colorado River, the model program automatically calculates the costs at the baseline salinity level[35]. The incremental difference in damages are those that might be properly attributed to River salinity, particularly if the difference is expressed as a range between two baselines.

[35]The projected salinity levels will be based on future scenarios of water depletions and hydrology used in the Bureau of Reclamation's Colorado River Simulation System (CRSS).

chapter 5

ECONOMIC DAMAGES TO WATER AND WASTEWATER UTILITIES

Types of Economic Damages to Utilities

The corrosion caused by constituents of saline water and the scale deposited by hard water affect the useful life of household water piping and wastewater piping, as discussed above. An entirely identical effect occurs to the facilities of water and wastewater treatment utilities used for collection, treatment, distribution, and storage.

Over a period of years, the water utility's production, distribution, and storage system suffers damage from salinity-related corrosion or hard water scale that lessens the useful life of the system.

Similar salinity effects occur to the wastewater utility's collection and treatment system. The latter damages are expected to be more severe, since the use of municipal and industrial water adds incremental salinity, on the order of 250 mg/L, to the salinity of the water supply. However, for purposes of this study, salinity added by M&I use cannot be attributed to salinity of the Colorado River[36] and thus has been ignored.

Although these damages fall directly on the water or wastewater utility, they are passed along to the utility customer in the form of high rates or in taxes, so it is appropriate to consider them a form of household damages. They are identified in this study as Utility Damages, which are calculated both as a metropolitan area total and as damages for households.

The effect of salinity on water and wastewater utility facilities has been determined by Tihansky, according to the following formulas relating facility life (in years) to salinity level (in TDS), t, where e is the natural exponential (approximately 2.71828):[37]

Water supply system (production), life = $30.83 - 0.0033t$

Water supply system (distribution), life = $60 + 50e^{-0.0009t}$

Storage tanks, life = $50.83 - 0.0033t$

Sewage facilities, life = $30.83 - 0.0033t$

Table 10 shows the useful life as developed from Tihansky's data for water supply production and distribution systems and for sewage facilities.

No equivalent table was prepared on the useful life of storage tanks, for two reasons: first, the investment in storage facilities is relatively low compared with the investment in production and distribution systems; and second, the data the authors obtained did not always separately identify storage facilities nor indicate whether

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[36] There is one exception. The hardness of saline Colorado River water stimulates the use of residential and commercial water softeners, which add salt (NaCl) to wastewater when the softeners are regenerated.

[37] Tihansky, Damage Assessment of Households, p. 908. Slightly different formulas for useful life, and formulas for annual operations and maintenance costs, appear in an earlier Tihansky article: Dennis P. Tihansky, "Economic Damages from Residential Use of Mineralized Water Supply," Water Resources Research, Vol. 10, No. 2 (April 1974), pp. 145-154. Tihansky developed these formulas from the observations of earlier published research studies, many of which are cited in chapter 4 of this report.

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Table 10. – Useful life of water supply production and distribution systems and wastewater utility systems

TDS Level (in mg/L)	Water Utility Production System (years)	Water Utility Distribution System (years)	Wastewater Utility System (years)
0	30.83	110.00	30.83
100	30.50	105.70	30.50
200	30.17	101.76	30.17
300	29.84	98.17	29.84
400	29.51	94.88	29.51
500	29.18	91.88	29.18
600	28.85	89.14	28.85
700	28.52	86.63	28.52
800	28.19	84.34	28.19
900	27.86	82.24	27.86
1000	27.53	80.33	27.53
1100	27.20	78.58	27.20
1200	26.87	76.98	26.87

they were storage tanks or storage reservoirs. If better data become available in the future, the model can then be amended to deal separately with storage tanks.

The authors were fortunate to obtain data on the population served and on the replacement cost (separated for production and distribution facilities) of several of the water supply systems of the major metropolitan areas served with Colorado River water. These came from unpublished data from the American Water Works Association's Survey of Operating Data for Water Utilities, 1984.[38]

Although the estimates of replacement cost were made during 1985, they have been considered as current (1986) estimates; indexing the values to 1986 is considered unnecessary because of the limited precision of the data. The replacement cost estimates for Phoenix, Tucson, Las Vegas, Los Angeles, Orange County (Anaheim), Riverside County (Eastern MWD), and San Diego were divided by the population served by the water utility to calculate 1986 Capital Investment Cost Per Capita. Similar costs per capita were calculated for the Metropolitan Water District of Southern California, which may appropriately be added to the per capita costs of the counties served by MWD. No data were obtained for that portion of San Bernardino County (i.e., Chino Basin) served by MWD, so values for Riverside County are suggested for use. No data were obtained for the various Colorado River Mainstream towns, so a rounded average of values for the other areas was substituted. The resulting data are shown in table 11.

No similar survey of wastewater utilities could be located, although inquiries were made of the Water Pollution Control Federation and the Association of Metropolitan Sewerage Agencies. Instead, data on facility investment were obtained from the annual reports of two large wastewater agencies: San Diego and Phoenix.[39] The data used were capital investment in facilities, equipment, and construction in progress, without deducting accumulated depreciation. Thus, the data represent historical cost rather than replacement cost.

Calculated capital investment cost per capita was $334.98 for Phoenix and $350.24 for San Diego. No attempt was made to index these figures to 1986 because of the limited precision of the data. Because of the close agreement of these two values, a rounded approximation ($350.00) was used for the other metropolitan areas.

[38]The AWWA conducts periodic national surveys of member water utilities, of which the survey of 1984 operating data (conducted in 1985) sought data on the replacement costs of the total water system. The following categories of data on facility replacement cost were obtained: water source, including raw storage; pumping; treatment; distribution system; finished water storage; and general property. For purposes of the current study, the first three categories were combined as "Production System," and the next two categories were combined as "Distribution System." General property, including land and buildings, was not used. Data from the questionnaires were obtained through the courtesy of George L. Craft, P.E., AWWA Headquarters, Denver, on November 18, 1986, and January 14, 1987.

[39]City of San Diego Water Utilities Department, Annual Financial Report, FY Ended June 30, 1985, p. 34; and City of Phoenix Water and Wastewater Department, 1983-1984 Annual Report, cited in response to AWWA Survey of Operating Data for Water Utilities. Only these two areas were used as a data base because of limited time and project resources.

Table 11. – Capital investment cost in 1986 per capita for water supply production and distribution systems

Metropolitan Area	Water Utility Production System	Water Utility Distribution System
Phoenix	163.70	859.26
Tucson	332.73	1191.00
Las Vegas	151.23	1344.80
Los Angeles Co	1015.65	2012.14
Orange County	91.05	962.32
Riverside County	183.23	1495.47
San Bernardino Co	183.23	1495.47
San Diego	287.01	836.13
MWD of So. Calif	241.86	228.68
L. Colo. River Area	200.00	1000.00

The annual economic damages to utilities from salinity corrosion and hard water scale are represented by the increased cost of facility and equipment replacement due to the reduction in useful life at higher TDS concentrations. Damages are calculated by dividing the capital investment cost per capita by the years of useful life at a predicted TDS level, then repeating the calculation with the longer useful life at a lower baseline TDS level. The difference in the two values represents the annual damages per capita attributable to salinity. This value can be converted to total annual damages for a metropolitan area by multiplying by the population. The annual damages per household can be calculated by dividing the total metropolitan area damages by the number of households.

Estimating Current and Future (1987-2010) Damages to Utilities

The computer model automatically calculates the total utility damages, and damages per household, for one or all metropolitan areas in the Lower Basin, for a selected year or for a specified period of years. The damages are identified by type, i.e., water utility production system, water utility distribution system, or wastewater utility system, as well as the total damages for all three types.

The computer model displays, and invites the user to change, data on 1986 Capital Investment Cost Per Capita for each of the three utility systems for each of nine metropolitan areas. Population data for these metropolitan areas had previously been displayed in the Household Damages segment of the model and the user was invited to change the data if appropriate. Once accepted without change, or changed, the same population data are used to calculate Utility Damages.

Next, the computer model displays, and invites the user to change, data on useful life (in years) of each of the three utility systems. After the metropolitan area[s] and year[s] are selected by the user, the model determines the TDS level (from Part II, step b) and determines the useful life of each system corresponding to that TDS level. The model divides the 1986 Capital Investment Cost Per Capita for each system by the Useful Life (in years) to determine the Annual Damages Per Capita. The model also multiplies the Annual Damages Per Capita by Population for the appropriate year to determine total damages for the metropolitan area, for each system. These values are summed by metropolitan area and by the selected years to generate Total Damages and (through the previously determined value of Average Number of Persons Per Household) Damages Per Household. These data are displayed either as a table or a bar graph or both, and either or both can be printed if desired.

chapter 6

POLICY INDUCED DAMAGES TO WATER AND WASTEWATER UTILITIES

One of the more significant costs of salinity is occurring in an area of damages that has not heretofore been investigated. That is, the costs to a water supply or wastewater treatment utility that are imposed by government regulation or by the necessity of providing less saline water for first use or reuse. Those costs imposed on utilities by regulation or the necessity to lower salinity to meet a desired or mandated quality level represent costs that are just as real as costs of salinity related corrosion or scale, and potentially much more expensive.

In one area using Colorado River water, significant salinity-related regulatory costs that are now being imposed on utilities affect water use and project planning procedures and require amounts of capital equal to one half the entire amount thus far budgeted for the Colorado River Salinity Control Program. That area encompasses the Santa Ana Watershed in San Bernardino, Riverside and Orange Counties in southern California. To date, the Santa Ana Watershed Project Authority has spent $50 million (in 1986 dollars) in capital costs directly in response to regulatory requirements for reducing salinity in water. Another $250 million in capital costs are already scheduled or being planned before the year 2010. Most, but not all, of this expenditure can be directly attributed to Colorado River salinity.

Costs Imposed by Regulation

Many of the costs that have been and are likely to be borne by various water utilities are the direct result of actions taken by regulatory agencies.

The *Santa Ana Watershed Project Authority (SAWPA)* represents the fullest picture of the potential impact of salinity regulations on utility costs. The Authority evolved from a planning agency in 1972 which was established to cross political boundaries. It currently represents municipal water districts in San Bernardino, Riverside, and Orange Counties (Eastern and Western Municipal Water Districts of Riverside County, Chino Basin, San Bernardino Valley Municipal Water District, and Orange County Water District) with a population of about 4,000,000 (projected to grow to about 5.3 million by 2010) spread over a 2,200 square mile watershed. Its goal is to maximize water reuse in the Santa Ana River watershed, primarily through control of salinity buildup. The incremental TDS added by each water use is, in the SAWPA area, generally considered to be 250 mg/L. The Santa Ana Regional Water Quality Control Board requires that water in the Santa Ana River where it enters Orange County is to have a TDS of 600 mg/L or less. Meeting this water quality standard requires a combination of actions – wastewater treatment, brine disposal, water supply modification, and some desalting.

Another objective established by the Santa Ana Regional Water Quality Control Board is that water or wastewater used for groundwater replenishment be either not more than 600 mg/L TDS or no more saline than present groundwater, whichever is less. Another water quality regulation requires that water used for injection into the Orange County coastal sea water intrusion barrier not exceed 540 mg/L TDS and meet drinking water standards. The combination of these two regulations has required substantial capital and O&M expenditures since the the early 1970's.

SAWPA has already expended $50 million in capital costs in planning and on the construction of a brine line that extends from Riverside County to an ocean outfall. The brine line capital cost was $50 million (in 1986 dollars), including treatment facilities purchased from Orange County Sanitation District, and the pipeline has a book value, after five years depreciation, of $32 million. The line has an 30 mgd capacity for flow to remove water exceeding 1,000 mg/L TDS. SAWPA owns rights to 30 mgd of treatment capacity in Orange County Sanitation District facilities but currently is using only 8 mgd of its capacity. The pipeline is carrying 4.5 mgd of saline domestic and industrial waste for a $392 per million gallon treatment and O&M charge. The brine line is going to be extended into San Bernardino County at a capital cost of $30 million. The O&M costs of the extension will remain in the same range as the present costs – a mixture of treatment, administration, actual O&M, and replacement costs that are adjusted each year.

SAWPA also is planning to construct a desalting plant to make use of ground water from the Arlington Basin water at a capital cost of $15 million. The desalted water is to be sold to MWD at a price determined by a formula, currently about $360 per acre-ft., to recover all or part of O&M expenses.

The desalter is part of the plans being formulated to solve the serious problems of the Arlington area which is primarily dependent on Colorado River water. After one agricultural application the Arlington groundwater is averaging about 1,000 mg/L TDS with high nitrates, thus rendering it unsuitable for domestic use. In addition the water is migrating toward the Santa Ana River. The desalter will solve only part of the problem and a plan has been formulated to convert the area to State Project water – reducing TDS additions by 500 mg/L. SAWPA estimates that the required 60-inch pipeline to bring the water from Arlington to Corona will cost $25 million, and the cost of State water is expected to be $320 to $420 per acre-ft.

The SAWPA area is also under pressure from the Santa Ana Regional Water Quality Control Board to resolve wastewater treatment problems in the lower Riverside-Corona area. A regionalization of the treatment capacity is being considered at a $95 million capital cost by 2000, $13 million of which will be spent by 1990. In addition, demineralization may have to be added to the plans to maintain the 600 mg/L TDS river objective. A tertiary wastewater treatment plant is also being required by the Water Quality Control Board for the Western MWD of Riverside County and the San Bernardino MWD. The capital costs by 1987 will be $50 million.

Actual and Planned SAWPA Costs

In sum, the expended and proposed investment of SAWPA to address the problems of high TDS water amounts to approximately $250 million (1986 dollars) – just about half of the proposed amount to be spent for the entire Colorado River Salinity Control Program. In addition, the identifiable O&M costs of the SAWPA project users currently amount to about $6,000,000 per year for brine line transport and treatment. When the desalting plant or plants become operational, the amortization and O&M costs per acre foot of desalted water will be between $375 and $400. When State Project water is substituted for Colorado River water in the Arlington Basin the costs per acre foot will be about $370,[40] more than MWD is currently scheduled to pay for the desalted water. With these figures, it is apparent that the costs of addressing salinity are high and are increasing in the Santa Ana watershed of Southern California. The capital costs alone will eventually amount to more than $256 million in the watershed, and brine line O&M costs will eventually reach over $11.0 million per year. J. Andrew Schlange, Manager of SAWPA, puts it succinctly when he states that the agency is spending $25 million to remove 12,000 tons of salt per year. That equates to $2,000 per ton of salt removed, or about 20 times as costly as the cost-effectiveness for some Colorado River Salinity Control Projects now under construction.

Costs for Local Water Utilities

The San Bernardino Valley Municipal Water District has a much smaller but growing salinity-related problem. The District will face a future need for water to supplement its existing water

[40] The cost of State Project water has been estimated by interviewees throughout the MWD service area. The range quoted and average cost used represents a compilation of these estimates.

supplies. Not only is Colorado River water unacceptably saline because the District is high in the watershed and provides dilution water for Riverside County discharges, Colorado River water also is not readily accessible. As a result, the District will continue to purchase supplemental State Project water. The present cost of State water purchases is $15 million per year ($37.50 per person annually). The future cost of supplemental water purchases will rise to $20 million per year by 2010 (about $50.00 per person annually). Part of this cost can be attributed to salinity control as this State Project water serves to reduce salinity in water discharged in Riverside County through its contribution to dilution.

Orange County Water District, through its Water Factory 21, also has incurred large costs attributable to salinity. Neil Cline, former General Manager, states that all of the costs of Water Factory 21 and about 10 percent of general administrative costs of the District can be attributed to salinity-caused restrictions and response to regulatory measures. The primary regulation is, of course, constraints on the TDS level of water that can be injected into the seawater intrusion barriers along the Orange County coastal area. Regional Water Quality Control Board rules require that such water be no more that 540 mg/L TDS. Since the wastewater flowing into Water Factory 21 comes from the Santa Ana River and local wastewater treatment plants at a current 700 mg/L TDS, treatment is required for salt load reduction as well as for normal wastewater contaminants before injection.

Water Factory 21 was constructed, beginning in 1972, at a capital cost of $16.2 million amortized over 20 years (at 7 percent interest). Ongoing capital projects for the Factory average about $50,000 per year. In 1986 the O&M cost of Water Factory 21 was $2.5 million, with another $450,000 in laboratory and research costs. Much of the annual expense is for energy, membranes, chemicals, etc., associated with the reverse osmosis process. The current RO cost is $415 per acre-ft, but in-plant research may lead to a reduction to $375 per acre-ft once investment is made in more versatile pumps and low pressure membranes.

Another factor in Orange County that relates to salinity is the availability of water for reuse. According to Neil Cline, about 200,000 acre-ft per year of wastewater are currently dumped in the ocean. This water will eventually have to be replaced, as population increases, at a cost of (in 1986 dollars) $1.8 million for Colorado River water or $7.4 million for State Project water. Current reuse in Orange County is about 4,000 acre-feet/yr (afy) of 900-1,000 mg/L TDS water. The Orange County Water District is proposing an expanded reuse program to 15-20,000 afy at a capital cost of $13 million plus $15-16 per acre-ft for conventional wastewater treatment. Any increase in salinity of the effluent to be reused would require demineralization at a cost of about $375-400 per acre-ft plus an increase in plant capacity requiring about $15.0 million in capital cost. The insidious effect of increasing salinity in Orange County not only would scrap plans for increased reuse unless expensive demineralization were instituted, but also could require acquisition of more State Project water from MWD. Finally, since RO removes only 90 percent of the TDS, more and more water will have to be desalted to achieve the required blend for reuse or injection as salinity levels increase upstream.

Impacts of Regulatory Decisions

Most of the costs to the water users in the Santa Ana watershed and in the Orange County coastal area have been incurred as a result of rules promulgated by the California Regional Water Quality Control Boards. The groundwater protection requirement of a maximum 1,000 mmhos electrical conductivity (640 mg/L TDS) and 540 mg/L TDS for coastal barrier protection have required over a quarter of a billion dollars in actual and planned expenditures. Those rulings are not likely to change except for the most severe type of water emergency.

Other areas of southern California have Regional Water Quality Control Boards with somewhat different rules and philosophies since both the water supply and geographic problems are different. Arizona will be facing similar issues as the Central Arizona Project becomes fully operative. The SAWPA experience may serve as a basic model for some of the areas, either in management or in structural solutions.

Present or Potential Policy Decisions

San Diego.

The San Diego Regional Water Quality Control Board has just about eliminated protection of groundwater basins from its mission. Of 19 identified basins in the San Diego region, 14 are already classified as beyond recovery or not worth redemption. The most critical problem in San Diego is the absolute need for more water and the Regional Board is attempting to resolve issues regarding water reuse. For the next 20 years the San Diego Board will not control the salinity of imported water since the need for more water outweighs most quality issues. Demineralization may very likely be necessary simply to provide potable water. Although the Board is actively promoting reuse, water of 1200 mg/L TDS is about the maximum usable even for landscape irrigation since the area's soil is predominantly heavy clay.

Los Angeles.

The Los Angeles Regional Water Quality Control Board, which covers Los Angeles and Ventura Counties, is able to take a more flexible approach to salinity. Unlike San Diego, this area receives a large proportion of water from the State Project, from the Owens Valley and from Mono Basin. The City of Los Angeles uses only about 4 percent Colorado River water in its supply. While the less saline water supplies of Los Angeles may be threatened by the law suit over the environmental consequences of interbasin diversion from the Mono Basin or by increasing salinity of State Project water, the probable schedule for receiving increasingly saline supplies is beyond 2010. The Los Angeles Board does set TDS limits for wastewater discharge, but they range up to 3000 mg/L since most of the treatment plants are next to and discharge effluent in the ocean. Effluent limits ranging from 400 to 900 mg/L are set for those plants that deliberately or incidentally recharge groundwater basins, limits dependent on the quality of the receiving water.

Due to the nature of the Los Angeles region and based on the past behavior of that Regional Water Quality Control Board, it is uncertain what response to a water quality crisis would have on existing discharge limits or requirements for active measures to reduce or treat salinity. Reuse is not a major priority of the Los Angeles Water Quality Control Board since ocean disposal of wastewater and purchase of new water supplies will remain the preferred approach for the foreseeable future. This is highlighted by the failure of the Long Beach reuse project to convince nearby petroleum producers to purchase high quality reclaimed water at a much lower price than freshwater supplies for reinjection and secondary recovery. The decisive factor in their refusal was the inconvenience of further treating the reclaimed water to avoid conditions that could reduce the yield of the petroleum aquifer. Even though it would be cheaper to do so, the cost of water is presumably considered by the petroleum producers to be too low to make savings an incentive to change to a different supply. This position – the attractiveness of a familiar and consistent water supply – will be further discussed in the section on industrial water use (chapter 7).

Phoenix and Tucson, Arizona.

Arizona will be facing, in conjunction with new groundwater protection law, first time rules about saline water as the Central Arizona Project deliveries increase. Currently a fair amount of confusion exists about just what the CAP water can be used for. One body of opinion feels that it will be severely limited for groundwater recharge because of the new groundwater protection law. If that is the correct opinion, Colorado River water may have to be demineralized before many groundwater basins can be recharged with it. In addition, the health department may regulate drinking water salinity levels (although well water over 1,000 mg/L TDS is now used in some communities). Priorities of use according to the source of water may become a norm in Arizona but little can be predicted at this time.

At present Phoenix has few firm plans for the addition of CAP water for municipal use, and blending will take place only in areas of poor quality or shortage of supply. In the Phoenix metropolitan area blending with CAP water will substantially improve local water quality in many locations, but again plans appear to be uncertain. Tucson will officially begin receiving CAP water in January 1991 and is already planning to integrate the water into its first use and reuse system in a way that will not degrade groundwater basins or impede landscape irrigation with effluent. In effect, certain areas of Tucson will suffer degradation of municipal supply with the onset of CAP deliveries and other areas will not be impacted. Since Tucson already has a substantial penalty rate structure, local projections do not predict that the additional water supply will significantly increase per capita water consumption.

James Craig Tinney, in a draft of his doctoral dissertation [1986], states that Arizona water conservation goals, and the per capita reduction goals set by the Tucson area management plan to meet those goals, could have a deleterious salinity effect on the area's groundwater basins. This would occur as the proportion of CAP water to groundwater was increased to meet groundwater conservation goals. At the same time, management goals to increase water reuse and to restrict new agricultural development could also add to the salinity by indirectly recharging the groundwater with the increased TDS concentrations of effluent or by removing incentives for agricultural users to use low quality water in areas removed from city groundwater basins. Tinney argues that if "service areas cannot expand for water quality reasons then a cycle that picks up the saline recharge will be made."[41] With an incremental 200-300 mg/L TDS increase after each water use in an essentially closed system, the ultimate results on water quality can be predicted.

Las Vegas Valley, Nevada.

Current salinity levels in the Las Vegas area already exceed 500 mg/L throughout much of the water system. However, since Las Vegas draws its supply from Lake Mead, fairly high upstream on the Lower Colorado River system, it is not likely to face the degree of salinity damage that concerns southern California and Arizona. In fact, the contemporary position of the majority of water and wastewater officials in the Las Vegas Valley on regulation of salinity is to expect that regulation will not occur.

Summary of Policy Induced Costs

The regulatory costs imposed by salinity can be divided into several categories: capital costs; costs of procuring alternative water supplies; treatment for salinity; brine disposal; and costs of personnel devoted to addressing salinity issues. Some of the costs can be quantified while others can be described but not accurately measured.

Capital Costs.

The capital costs expended or already estimated in SAWPA and Orange County amount to about $264 million (in 1986 dollars).

Alternative Water Supply.

The costs of purchasing State Project water run between $320-420 per acre foot. The additional power costs for pumping may be as high as $210 per acre foot. In addition, the State Water Project does not provide an unlimited amount of water for the future. A further potential cost is that caused by loss of groundwater to salinity damage. If groundwater becomes too saline for use and cannot be demineralized, it must be replaced by an alternative water supply.

Treatment for Salinity.

The most widely used demineralization treatment in Southern California is reverse osmosis. The current cost for reverse osmosis at Water Factory 21 is $415 per acre foot. Research at the Factory is expected to result in a lowering of the cost to about $375 per acre foot in the reasonably near future.

Brine Disposal.

The brine line from Riverside County to an ocean outfall operates at a cost of $392 per million gallons ($1,203 per acre-ft – or up to $10.8 million per annum). The amortization of capital costs is included.

Personnel costs.

Personnel costs are difficult to estimate. Most of the staff costs of SAWPA and of the Santa Ana Regional Water Quality Control Board can be attributed as a cost of salinity

[41] James Craig Tinney, Draft doctoral dissertation [University of Arizona] Trading Quality for Quantity: Salinity Management Strategies for the Tucson Basin 1986, p. 45.

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control. Neil Cline, Manager of the Orange County Water District, states that 10 percent of his time and all the staff costs of Water Factory 21 can be attributed to salinity. About 40 percent of the Colorado River Board of California's budget is devoted to salinity matters. These costs can be substantial – figuring a very conservative average salary of $20,000 per year, the staff costs of the 100 or so people employed by these three organizations would be a $2,000,000 annual expense without inclusion of any fringe benefits or overhead costs. The Federal Government's staff costs for the Colorado River Water Quality Program in both the Denver Office and the Regional Offices amount to $3.7 million for Fiscal Year 1987, and do not include construction costs or the costs of other federal agencies.

Calculation of Value of Policy-Induced Damages

The costs imposed on water and wastewater utilities by regulation, or by a utility's decision that a water supply is too saline for first use or reuse, are very difficult to predict. They are the result of human judgment by regulatory agency officials or by utility managers, rather than the result of natural consequences (e.g., population growth, runoff, corrosion processes) that are more predictable. Because of the uncertainty surrounding the imposition of standards and the high variability of factors affecting costs (e.g., physical location of alternative water supplies), it was decided not to include this category of damages within the computer program. Instead, it is proposed that the program user calculate such damagaes through a separate analysis and add them to the other categories of damages which the program generates.

Nevertheless, some guidance can be given to the user in how to conduct these separate calculations, particularly those involving desalting by reverse osmosis. Other categories of costs, such as the purchase of alternative water supplies, pumping, and transmission costs associated with the collection and blending of this water with existing supplies, and brine disposal, can be quite variable and site specific. Calculation of these costs requires preparation of an engineering "reconnaissance" estimate based on a series of assumptions concerning sources of alternative supplies, their volume and cost, and the construction costs for aqueducts, storage reservoirs, treatment and distribution systems, brine disposal lines, and/or evaporation ponds.[42]

Still other types of costs are hard to calculate without a special analysis. An example is the direct costs of persons working for federal, state, and local agencies engaged in planning and construction of Colorado River salinity control measures and in responding to the problems caused by such salinity. They are relatively small, however, in comparison to the other categories of damages – probably in the range of $6 million - $7 million per year.

Calculation of desalting costs, using reverse osmosis, can be done by the following procedure:

1. Identify areas where (a) there is a regulatory limit on the TDS of water distributed, or discharged after use and conventional wastewater treatment, or used for groundwater recharge; or (b) where the TDS level of water is sufficiently high that the water supply agency desalts or blends it to reduce salinity (i.e., to meet desired drinking water standards for salinity or to avoid customer dissatisfaction).

2. If desalting is required, determine the design capacity of an RO plant, based on a 25-year useful life, as follows:

- Determine the desired TDS level of the water supply, T1
- Determine the highest forecast TDS level of the water supply over the following 25 years, T2. (This probably will occur at the end of 25 years.)
- Determine the estimated volume of water supply to be provided at the end of the

[42] It is presumed that many users of the computer model will have sufficient engineering estimating experience to recognize and surmount the complexities of preparing this type of estimate, using comparative costs and standard estimating data, such as appear in Bureau of Reclamation, Reclamation Instructions, Series 150, "Estimating." The estimating data can be kept current by using a construction cost index, e.g., the Bureau of Reclamation Construction Cost Trends, published semi-annually by the Construction Support Branch, D-1350, Bureau of Reclamation, P.O. Box 25007, Denver, CO 80225-0007.

following 25 years, in acre- feet/year, V1

The design capacity of the RO plant in acre-feet/year, V2, can be found by the equation:

$$V2 = \frac{V1(T2-T1)}{0.9\,T2}$$

3. The capital cost of an RO plant can be estimated (in 1986 dollars) as $1,240/acre-ft/yr in terms of design capacity. This can be converted to an annual sinking fund (i.e., annual cost of amortization which will accumulate to equal the invested capital cost at the end of the useful life) using an amortization formula. If the useful life of the plant is 25 years, with no salvage value, and the selected interest rate is 8 percent, the annual sinking fund factor is 0.0137 of the capital cost. This does not, however, provide for any return on the invested funds. It is more realistic to use a capital recovery factor (i.e., the annual cost of amortization plus a chosen rate of interest on the original investment) which will not only amortize the investment but provide some return on the invested funds. Again using a useful life of 25 years, an interest rate of 8 percent, and an 8 percent interest return, the annual capital recovery factor is 0.0937 of the capital cost. For each acre-foot/year of design capacity, the annual capital recovery factor in this example would be $116.

4. The O&M cost of operating an RO plant, based on anticipated costs at Water Factory 21, is $375 per acre-foot. The annual O&M cost would be based on volume of water desalted, rather than on design capacity.

Finally, it puts these policy-induced damages into perspective when we note that the Santa Ana watershed is spending $2,000 per year to remove one ton of salt from the area. This is 20 times as costly as the cost-effectiveness for some Colorado River Salinity Control Projects now under construction Yet this expenditure is considered worthwhile to the Santa Ana Watershed Project Authority membership.

Table 12 presents a summary of policy-induced costs for salinity control in the Santa Ana Watershed Project area.

Table 12. Summary of policy-induced costs for salinity control in Santa Ana Watershed Project Area (millions of 1986 $)

Capital Costs		Expended Through 1986		Projected/Possible
Brine Line		50.0		30.0
Water Factory 21		16.2	(until 2010)	1.2
Desalting Plants				
Arlington				15.0
Chino				28.0
Orange County				15.0
70 percent of Riverside Co. wastewater treatment				101.5
Total capital costs		66.2		190.7
Operating and Maintenance Costs		Current		Projected/Possible
Brine Line	5,040 af/yr	– 6.1	8,958 af/yr	– 10.8
Desalting Plant	6,988 af/yr at $415	– 2.9	56,000 af/yr at $375	– 21.0
Wastewater Treatment				unknown
Purchase of Alternative Water Supplies	40,000 af/yr	– 15.0	300,000 af/yr	– 111.0
Total annual O&M costs		24.6		143.4

chapter 7

ECONOMIC DAMAGES TO INDUSTRIES

Maximum Salinity Tolerances of Industrial Processes

Research identified six studies[43] that list water quality criteria for different types of industrial processes. Salinity is, of course, the criterion we are most interested in, and each of the studies lists different industrial uses of water with maximum TDS limits. The McKee & Wolf criteria, based on earlier studies by such organizations as the National Academy of Sciences and the Office of Water Research and Technology (OWRT), provide the most comprehensive listing. In particular, the OWRT study, which summarizes many of the earlier studies, lists criteria and treatment requirements for actual industrial water use rather than in the form of absolute standards. It says, "From the industrial viewpoint, the primary criterion is that the primary water supply be of consistent quality so that pretreatment [is] . . . maintained routinely."[44] Interviews and readings in the literature support this statement and it should be kept in mind when discussing saline water and industrial water uses. Salinity usually can be treated but constantly changing levels of salinity, or any other constituent, can cause the industrial water user some serious problems.

Certain industrial processes require TDS levels not exceeding a maximum that each of the studies agree upon. Among them are:

Primary metals – 1,500 mg/L TDS
Clear Plastics – 200 mg/L TDS
Confectionery Products – 100 mg/L TDS
Cooling Water – 35,000 mg/L TDS

Other industrial processes are presented somewhat differently in different studies. In particular, Culp, Wesner, and Culp seem to select conservative compromise values for many processes. The values presented here as ranges reflect the variations in values recommended in the various studies.

Textile manufacture – 100 to 200 mg/L TDS
Brewing, light – 500 mg/L
Brewing, dark – 1000 mg/L
Culp, Wesner, & Culp - 500 mg/L for both
Canning – 500 to 850 mg/L
Carbonated beverages –500 to 850 mg/L
General food processing – 500 to 850 mg/L
Ice making – 170 to 3000 mg/L
Pulp and paper – 80 to 1080 mg/L
Chemicals – 1000 to 2500 mg/L
Petroleum – 1000 to 3500 mg/L

The area in which the various studies disagree the most is that of boiler feed and make-up water. For example, EPA states that make-up water can be seawater (35,000 TDS) and doesn't mention pressures or primary feed water. The McKee & Wolf study doesn't mention pressure but provides a range of 50 to 3000 mg/L TDS for boiler water. The other studies can be broken into feed water for two different pressure ranges, less than 1,500 psig and from 1,500 to 5,000 psig as shown in table 13.

Clearly the most salt sensitive process can be high pressure boiler feed water, but there is some disagreement on upper salinity limits since, in fact, much of such water routinely is distilled. The OWRT caution about consistency of quality

[43] The five studies (the National Academy of Sciences study is incorporated, all or in part, in each of the five) are: McKee & Wolf, Water Quality Criteria, California State Water Resources Control Board, June 1, 1976; Office of Water Research and Technology, Industrial Wastewater Reuse: Cost Analysis and Pricing Strategies, Washington, D.C.: author, April 1981; Culp, Wesner and Culp, Water Reuse and Recycling: Vol. 1. Evaluation of Needs and Potential, Washington, D.C.: Office of Water Research and Technology, April 1979; U.S. Environmental Protection Agency, Quality Criteria for Water, prepublication draft; and Ernest Weber, unpublished lecture notes on salinity and water quality.

[44] OWRT, Industrial Wastewater Reuse, p. 19.

Table 13. – TDS of feed water in different pressure ranges

0-1,500 psig	1,500-5,000 psig	Investigator
50–3,500	0.0005–0.1	Culp
1,000–3,000	100–2,500	Weber
200–700	0.5	OWRT

would seem to be particularly relevant in this area.

Other salt sensitive processes are textile manufacturing, confectionery production, certain types of paper manufacturing, and clear plastics manufacture. In each of these areas, water quality standards appear to be so stringent that pretreatment of water from almost any source would be a prerequisite.

Industries Affected by Colorado River Salinity

Identification of water using industries in a particular area is a difficult task under any circumstances due to the proprietary nature of many plants and a reluctance to discuss processes, specific costs, etc. However, the Orange and Los Angeles Counties Water Reuse (OLAC)[45] Study did do an extensive survey of southern California water-using industries as a part of its study to determine a market for reuse water. This survey, by Montgomery Engineers in 1981, conducted 250 on-site interviews of industrial water users in Orange and Los Angeles Counties. Interviews conducted in 1986 during the course of the present study indicate that the 1981 survey results are still the best source of information on water using industries in southern California as there is little industry in San Diego, San Bernardino or Riverside Counties.

The OLAC study classified water users into "B" and "C" types. "B" users could accept wastewater plant effluent averaging TDS of 667 mg/L without additional treatment. "C" users would require the addition of lime softening before accepting effluent for use.

Los Angeles County has the vast bulk of industrial water users in southern California, including metals, textiles, chemicals, paper products, glass, and general manufacturing. There were, in 1981, 53 metal plating and other metal industry firms capable of using 3,370 acre-ft per year (afy) of "B" quality water. There were also 20 metals firms that could use 1,519 afy of "C" water.

There were two textile manufacturers able to use 480 afy of "B" water, and 10 which could use 3,023 afy of "C" quality water. Table 14, with Standard Industrial Classification (SIC) Code, illustrates the type of water use for Los Angeles and Orange Counties industries in 1981 – use that has not changed a great deal according to available sources.

Table 14. – Type of water use for industries in Los Angeles and Orange Counties in 1981

		B users 667 TDS		C users lime softening	
SIC		No	AFY	No	AFY
344	metals	55	3,793	20	1,519
222-7	textiles	2	480	10	3,023
3999	gen mfr	36	6,255	13	2,051
496	steam plant			1	1,800
281	chemicals	6	987	5	3,218
3652	records	1	84	1	100
291	petroleum	1	175	11	26,701
327	cement	1	19	1	330
262-5	paper	4	1,777	2	2,298
322	glass	3	7	3	67
282	plastics			1	200
327	gypsum	2	975		

A review of *County Business Patterns* since 1981 indicates a relatively slight change in industrial growth in the two counties. In addition, the OLAC study director, Dr. Wiley Horne, has remained active in the field and is now Director of Planning for the Metropolitan Water District of Southern California (MWD). In a 1986 interview, Dr. Horne stated that the OLAC survey figures still present a good picture of water using

[45]Orange and Los Angeles Counties Water Reuse Study, Mid-Course Report, 1981; Facilities Plan, 1982. Los Angeles: author.

industry in southern California. Although not reflected in this list, refinery cooling represents 80 to 85 percent of all industrial water use and potential water reuse in southern California. At the current 400 to 550 mg/L TDS levels available, the refineries get about six cycles from their cooling water – which brings discharge to at least 2550 mg/L TDS. This final discharge level supports the OLAC report statement that recycling water beyond an initial use level of about 2240 mg/L TDS will require special efforts at controlling corrosion. It may also require demineralization for uses other than cooling water.

This area of industrial damages from saline water is another in which there are insufficient data. However, the six studies do list water quality criteria for different types of industrial processes that appear in the Census of Water Use in Manufacturing. By using data from County Business Patterns for the major counties involved, along with current average TDS levels, it is possible to estimate salinity damages for two groups of industries – food processing and paper mills. Thus the industry, its location in the Lower Basin, and its annual average water use for processing/production can be estimated. The water quality criteria for these industries ranges from 500 to 850 mg/L TDS for food processing to 810 to 1080 mg/L TDS for paper mills.

Costs of Industrial Water Treatment for Saline Water

The Culp, Wesner, and Culp report describes the costs for a number of treatment process trains to prepare water for reuse. These treatment trains begin with sewage in its untreated state and take it through various types of primary, secondary and tertiary treatment, ending with reverse osmosis for demineralization and production of very high quality water for high pressure boilers and other uses requiring water purity. The treatment trains are costed for chemicals, energy, etc., but are not broken into individual components that might be used by an industry in treating freshwater supplies.

The OLAC study also deals with sewage, but only with sewage effluent that has undergone at least secondary treatment. Two processes that might apply to industry rather than to utility uses are costed in terms of capital investment and yearly operating and maintenance expenses – lime softening and filtration of secondary effluent. Lime softening is costed for quantities ranging from 0.5 to 21.0 million gallons per day (mgd) and shown in table 15; direct filtration is costed for from 1.0 to 5.2 mgd and shown in table 16. Economies of scale are factored into these 1985 cost estimates presented in the OLAC study.

Table 15. – Capital and O&M costs for lime softening of secondary effluent

mgd	Capital Investment	Yearly O&M
0.5	$ 1,400,000	$ 171,000
1.0	1,700,000	272,000
1.5	2,250,000	315,000
2.0	2,720,000	403,000
4.0	4,320,000	898,000
5.2	5,000,000	743,000
8.5	6,600,000	867,000
17.0	11,300,000	1,232,000
21.0	12,000,000	1,370,000

Table 16. – Capital and O&M costs for direct filtration of secondary effluent

mgd	Capital Investment	Yearly O&M
1.0	$ 705,000	$ 89,000
3.3	1,410,000	182,000
4.9	2,000,000	251,000
5.2	2,300,000	253,000

The operating and maintenance expenses are not only directly related to the quantity of water softened but also are affected by the need to transport the water and quality of the water to be softened. These expenses do, however, provide a contemporary and site specific (in terms of topographically caused expenses) estimate of the costs of softening water in the 500 mg/L TDS range.

Direct filtration costs exhibit fewer site-specific variables than lime softening. In these costs the economies of scale are clearly visible.

The most common and widely accepted method of reducing the TDS level of any water prior to use is by a membrane process such as reverse osmosis (RO) which generally removes about 90 percent of the dissolved solids. Although the RO process is extremely energy intensive, research taking place at Water Factory 21 in Orange County indicates that improvements in low pressure membranes and in cleaning the membranes will lead to some significant cost savings. The current cost of producing an acre foot of RO water at Water Factory 21 is $415. It is anticipated that the cost can be reduced to $375 per acre foot. Although this water has had advanced treatment before going to the RO system, the TDS levels going in are about 720 mg/L. Water Factory 21's system removes 90 percent of this TDS. The capital costs of an RO system are dependent on the size of the installation. At Water Factory 21 the costs were about $16 million for the entire plant, including all treatment facilities. The rule of thumb for capital costs of constructing an RO plant is $2,000 per gallon per minute capacity. Therefore, current capital costs for a 1 mgd plant would be about $1.4 million if the intake water needed no other type of pretreatment. The probable industrial use of water requiring such refined treatment, based on the OLAC survey, is not likely to exceed 1500 afy – just about 1.3 mgd.

Estimating Current and Future (1987-2010) Salinity Damages to Industry

The computer model automatically calculates the total salinity damages (and separately calculates capital investment expenditures and annual operation and maintenance expenditures) to industries in the Lower Basin. This is done for one or all metropolitan areas in the Lower Basin and for a selected year or for a specified period of years.

Conceptually, damages are considered to be the sum of (1) the annual capital investment in water treatment equipment required by all industries in the geographic area at the area's 1986 level of industrial development, at the forecasted TDS level for the selected years; and (2) the annual operating and maintenance expenditures on water treatment by these industries; minus (3) the annual capital investment that would be required at a selected baseline TDS level; and minus (4) the annual O&M expenditures at the baseline TDS level.

Because industrial damages in the industries studied did not occur before the TDS level reaches 500 mg/L, the program operator should remove those metropolitan areas that do not reach this standard at the selected current TDS value when the program offers that option. Further, since some industries require water treatment even if the M&I water supply is very low in salinity, it is appropriate to measure salinity damages as the difference in industrial damages at two or more separate TDS levels, one or two baseline levels and the other at the predicted level.

Because future industrial growth, either by volume or type of industry, is very difficult to predict, the growth in industry beyond the 1986 level is conceptually considered to be directly proportional to population growth.

The conceptual model uses the same data for future metropolitan area population by year, TDS data by year, and discount rate to calculate industrial damages as the model earlier used to calculate household damages. The new data required for the model are: (1) useful life (in years) of water treatment equipment; (2) amount of capital investment in new water treatment equipment, corresponding to TDS level, at the 1986 level of industrial development of the specified metropolitan area; and (3) annual operating and maintenance expenditures for water treatment equipment, corresponding to TDS level, at the 1986 level of industrial development of the specified metropolitan area. The new data have been calculated by the authors, as described earlier in this section, and are proposed for use until better data may become available from another source or follow-up analysis.

The computer model displays, and invites the user to change, the three items of new data. After the metropolitan area[s] and year[s] are selected by the user, the model determines the corresponding TDS level and then calculates the capital investment in new water treatment equipment and the annual O&M expenditures for water treatment. The model then calculates the annual or discounted value of capital investment based on the useful life of water treatment equipment and the preselected discount rate.

Next, the model extrapolates both the annual value of capital investment and the annual O&M expenditures by indexing them to future population growth over a 1986 population base that meets the 500 mg/L TDS level at which industrial damages begin to occur in the industries studied. The capital investment and O&M expenditures are displayed by year, by metropolitan area (or all areas), either in tabular form or as a line graph. Either or both forms of display can be printed.

chapter 8
SUMMARY OF DAMAGE ESTIMATES

The computer model has been operated to produce estimates of damages under various assumptions of current salinity level and baseline salinity level. These estimates are discussed below.

Current (1986) Salinity Damages

The 1986 salinity levels of the Colorado River were unusually low following an extended period of excess flows that diluted the salinity of the storage reservoirs. These levels are shown in table 17.

Table 17. — Salinity levels in 1986 *

Hoover	542 mg/L TDS
Parker	542 mg/L TDS
Imperial	579 mg/L TDS

* Provisional

Using these abnormally low salinity values in the model produces salinity damage estimates that are understated in comparison with the normal damages that have occurred and are likely to occur in the future. However, the damage estimates for the year 1986 are as follows:

Agricultural damages ranged from $15,612,000 to $25,282,000 in the Lower Colorado River Basin areas irrigating with river water in 1986. These were: Imperial and Riverside Counties, California, and Yuma and La Paz Counties, Arizona. No damages were included for the Central Arizona Project lands because deliveries of CAP water had not begun.

The $15,612,000 damage calculation, the lower bound of the range, is determined by using the 1986 actual TDS values as current levels and a baseline salinity level of 500 mg/L. The $25,282,000 upper bound of the range, is determined by using the 1986 actual TDS values and a baseline level of 334 mg/L TDS.

Household damages in 1986 ranged from $49,746,000 to $430,440,000 or from $22.94 to $73.45 per household in the area receiving M&I water containing some portion from Colorado River sources. The lower bound of the estimate is calculated using the current TDS values of River water and current assumptions of TDS of the blended supplies, along with a baseline salinity level of 500 mg/L TDS. The upper bound ($430,440,000) of the estimate is calculated using a 334 mg/L TDS baseline salinity level. The components of the damage estimates are:

	Range mg/L base	
Total household damages for 1986:	500	334
Household water pipes	$4,901,888	$46,383,584
Household waste-water pipes	3,525,392	35,142,016
Water heaters	1,666,628	17,635,872
Faucets	950,384	8,938,048
Garbage grinders	614,968	5,647,704
Toilet flushing mechanisms	49,445	423,545
Clothes washers	1,976,208	19,531,168
Dish washers	768,516	7,595,392
Bottled water purchases	3,281,352	21,964,800
Home water treatment systems	12,767,680	128,397,664
Soaps and detergents	1,073,944	10,859,310
Clothes replacement	1,095,864	10,902,070
Automotive cooling systems	17,073,568	117,018,528
Total	$ 49,745,837	$ 430,439,701

Utility damages in the metropolitan areas receiving some Colorado River water in their M&I supply in 1986 ranged from $1,162,000 to $15,781,000, or from $0.54 to $2.70 per household. As with household damages, the lower bound was calculated by actual 1986 salinity levels and a baseline of 500 mg/L TDS, while the upper bound is calculated using a 334 mg/L baseline. Details of utility damages are shown next:

Total utility damages for 1986:	Range mg/L base 500	334
Water utility production	$ 298,152	$ 4,341,504
Water utility distribution	$ 634,744	$ 9,190,272
Wastewater utility	$ 229,548	$ 2,249,536
Total	$1,162,444	$15,781,312

Industrial damages during 1986 ranged from $2,089,000 to $10,906,000. The lower bound is calculated using current 1986 blended TDS assumptions and a baseline level of 500 mg/L TDS. The upper bound uses a 334 mg/L baseline level. The components of industrial damages are:

Industry	Range mg/L base (In $1000's) 500	334
Capital investment	$224.30	– 1,170.63
O&M costs	$1,865.12	– 9,735.63
Total damages	$2,089.42	– 10,906.26

Policy-related damages for 1986 include annual capital costs for investment in facilities and annual operating and maintenance costs. These are estimated at $7,950,000 for annual capital costs, assuming a straight-line average investment (in 1986 $) from 1987 to 2010, and $24,600,000 for annual O&M costs (in 1986 $). This totals $32,550,000 annually.

Total damages, based on actual 1986 Colorado River salinity levels, range from $101.2 million to $515.0 million annually, as shown below.

Total damages for 1986	Range mg/L base 500	334
Agriculture	$ 15,612,000	25,282,000
Household	49,745,000	430,440,000
Utility	1,162,000	15,781,000
Industry	2,089,000	10,906,000
Policy-related	32,550,000	32,550,000
Total damages	$101,158,000	514,959,000

Figure 8 summarizes the annual damages based on 1986 TDS for both the 500 and 334 mg/L baselines.

Figure 9 summarizes the annual damages based on 1986 TDS and a 500 mg/L base.

Ten-Year Average (1976-1985) Salinity Damages

The average levels of Colorado River salinity during the 1976-1985 period reflect more normal conditions of river flow as well as a period of excess flows. Therefore, they are considered more representative of past and probable future salinity conditions than the abnormally low 1986 salinity level. The 10-year average salinity levels at the three major reservoirs of the Lower Colorado River mainstem are shown in table 18.

Table 18. – Salinity levels for 10-year average (1976-1985)

Hoover	652 mg/L TDS
Parker	678 mg/L TDS
Imperial	767 mg/L TDS

Damage estimates have been calculated by the computer model based on these values and on two selected baseline salinity values, 334

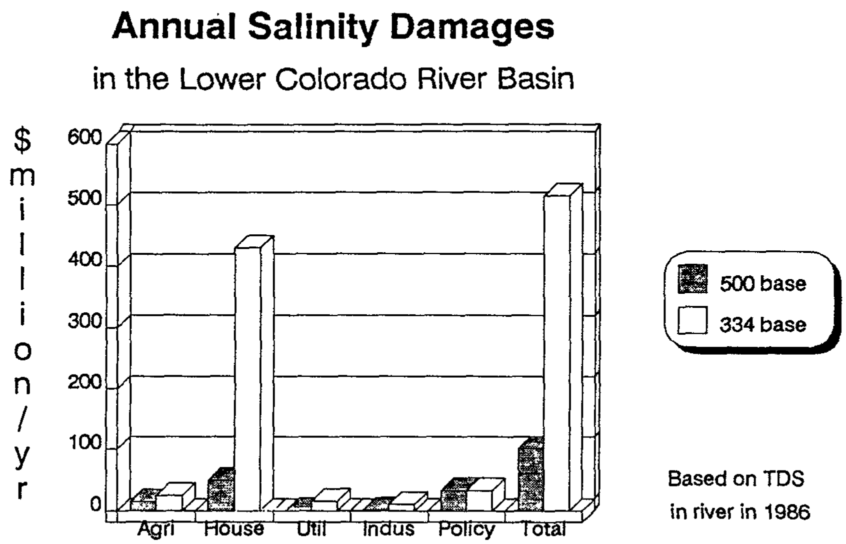

Figure 8. — Annual salinity damages based on TDS in river in 1986 for both the 500 mg/L and 334 mg/L bases.

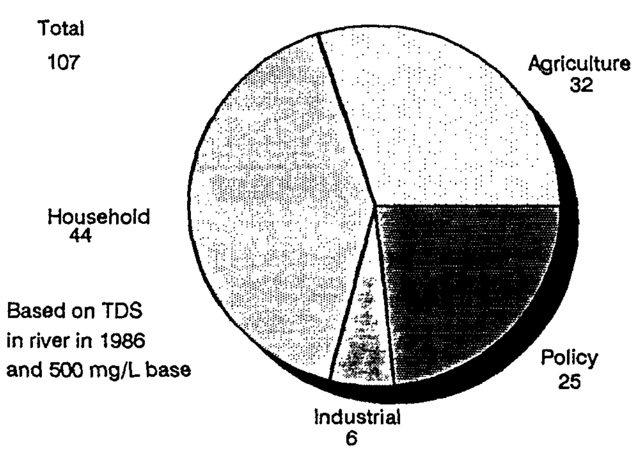

Figure 9. — Annual salinity damages based on TDS in river in 1986 and the 500 mg/L base.

mg/L and 500 mg/L. These two combinations of 10-year average and baseline levels generate estimates that bound the range of damages. They are described below.

Agricultural damages ranged from $112,800,000 to $122,470,000 in the agricultural counties of Imperial, Riverside, Yuma, and La Paz. No damages occurred in the Central Arizona Project area because deliveries had not begun in this period.

Household damages ranged from $156,114,000 to $637,575,000, or from $64.76 to $108.81 per household. The components of the household damage estimates are as follows:

Total household damages for 10-year average:	Range mg/L base 500	334
Household water pipes	$ 14,373,424	65,660,320
Household wastewater pipes	10,349,648	49,351,872
Water heaters	4,683,624	24,198,448
Faucets	2,753,408	12,692,664
Garbage grinders	1,765,384	8,035,376
Toilet flushing mechanisms	151,276	618,934
Clothes Washers	5,872,960	27,817,664
Dishwashers	2,283,912	10,817,880
Bottled water purchases	11,777,472	36,058,384
Home water treatment systems	36,761,472	180,143,776
Soaps and detergents	3,093,546	15,213,278
Clothes replacement	3,158,032	15,346,246
Automotive cooling systems	59,089,376	191,620,256
Totals	$156,113,534	$637,575,098

Utility damages in the metropolitan areas using some Colorado River water in their supply ranged from $3,236,000 to $22,753,000, or from $1.34 to $3.88 per household annually. Details of utility damages are shown below:

Total utility damages for 10-yr average:	Range mg/L base 500	334
Water utility production	$ 767,400	$6,489,184
Water utility distribution	1,802,344	13,089,040
Wastewater utility	666,496	3,174,736
Totals	$ 3,236,240	$ 22,752,960

Industrial damages in the metropolitan areas receiving Colorado River water in their M&I water supply ranged from $6,115,000 to $15,799,000 annually. The components of industrial damages are:

Industry	Range mg/L base (In $1000's) 500	334
Capital investment	$656.39 –	1,695.85
O&M costs	$5,458.87 –	14,103.36
Total damages	$6,115.26 –	15,799.21

Policy-related damages for 10-yr average are estimated at $7,950,000 for annual capital costs and $24,600,000 for annual O&M costs (in 1986 $), or a total of $32,550,000 annually.

Total damages, based on the 10-year average salinity range from $310.8 million to $831.1 million annually, as summarized below.

Total damages, 10-year average	Range mg/L base 500	334
Agriculture	$112,800,000	122,470,000
Household	156,114,000	637,575,000
Utility	3,236,000	22,753,000
Industry	6,115,000	15,799,000
Policy-related	32,550,000	32,550,000
Total damages	$310,815,000	831,147,000

Figure 10 shows the annual damages based on the 10-year average salinity using the 500 mg/L base. Figure 11 shows the annual damages based on 10-year average salinity for both the 500 mg/L and 334 mg/L bases.

Total damages on a household basis ($ per household per year) for current (1986) conditions and the 10-year average as measured against the 500 mg/L and 334 mg/L baselines are shown in figure 12.

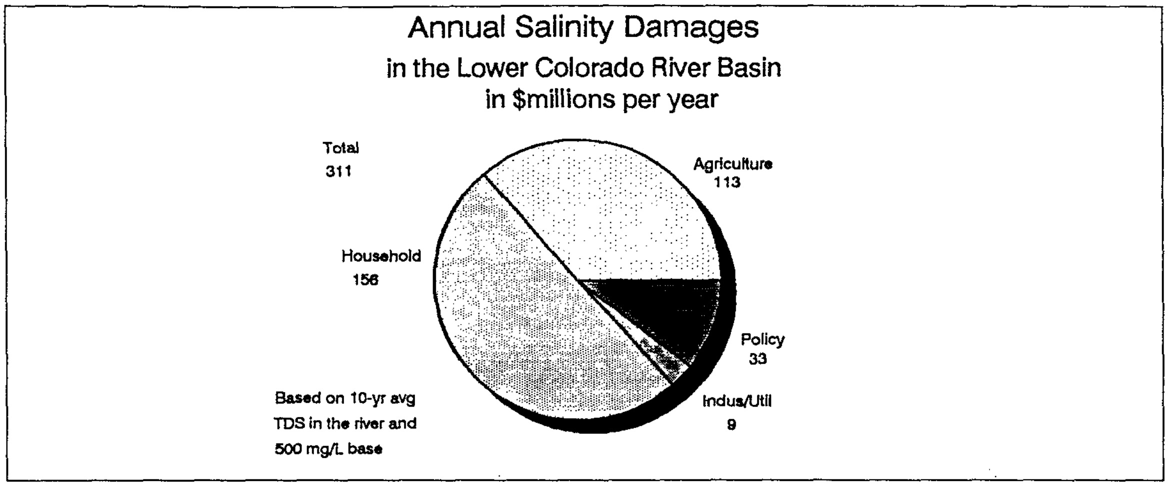

Figure 10. – Annual salinity damages based on 10-year average salinity and the 500 mg/L base.

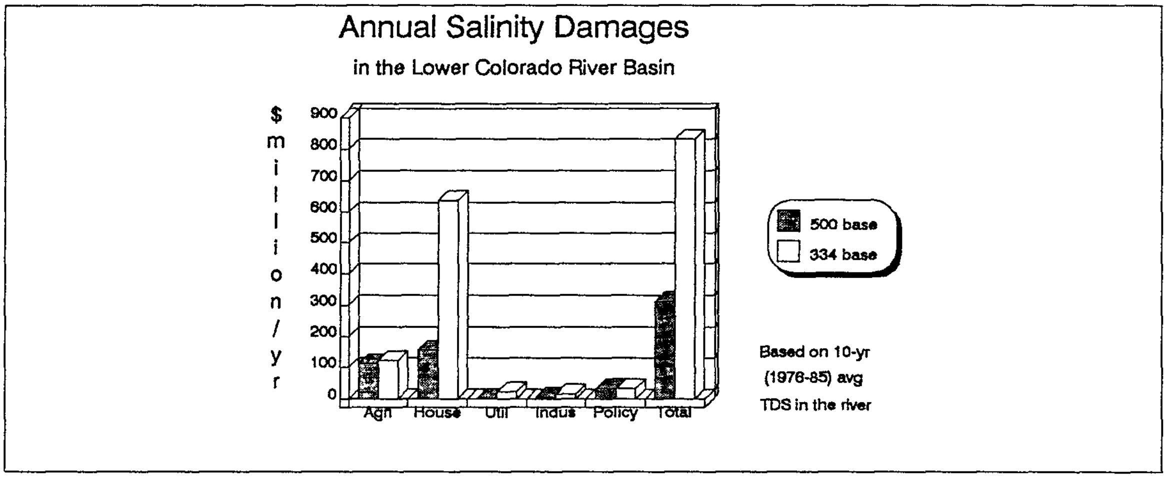

Figure 11. – Annual salinity damages based on 10-year average salinity for both the 500 mg/L and 334 mg/L bases.

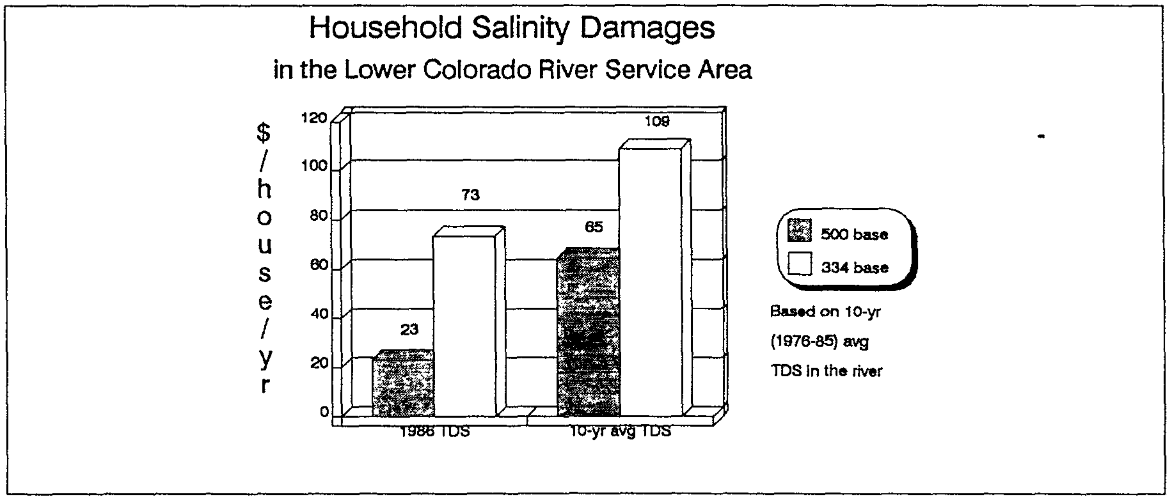

Figure 12. – Annual salinity damages per household in Lower Colorado River service area.

chapter 9
ISSUES AND QUESTIONS NOT ADDRESSED

Salinity is not always a liability. It can, in moderation, contribute positively to the health of some consumers and to the formation of protective scale in the plumbing systems of the average home. On the other hand salinity, when it does cause damage, can create secondary or indirect economic or social impacts along with the direct damage. Salinity of the Colorado River also has a serious impact on the agriculture and M&I uses of northern Mexico which continue to damage relations between the United States and Mexico.

Health Effects of Salinity

Available research into saline water (500-800 mg/L TDS) indicates that, for the average person, such water may not have any significant harmful effect on health. However, gastrointestinal effects have been noted at high levels of some constituents such as sulfates (over 600 mg/L) among persons unconditioned to such levels.

A 1977 study for EPA found that water-related morbidity and mortality depended on the specific inorganic or mineral constituents of the water.[46] Further the study found that hard water is linked to a decreased incidence of heart disease, hypertension, and strokes. A 1984 review of the literature on salinity related to health revealed no information differing from this study.[47]

There are relatively few individuals who must attempt to totally restrict sodium intake. For these, salinity is a problem that must be remedied by the purchase of sodium-free bottled water. A more likely circumstance is that hard water is softened, changing the chemical constituents and thus the taste. Softened water is likely to contain more sodium, which is undesirable for persons with high blood pressure or cardiovascular disease.[48]

Salinity also appears to protect the health of water consumers by reducing the risk of dissolving heavy metals. Rising levels of lead contamination in public drinking water supplies are now the subject of drinking water regulation. The lead does not occur naturally but comes from corroding pipes, faucets, and solder used in plumbing equipment. The anti-corrosive scale generally formed by saline water is the best natural barrier to the leaching of lead into drinking water supplies. Soft or softened water, on the other hand, can be harmful if the water is invasive and dissolves metals resulting in high levels of cadmium, lead, copper, and zinc.

Reduction of Corrosion

An advertisement in the December 1986 issue of the *Journal of the American Water Works Association* touts a new product, long in development, that forms a protective scale in water system pipes. Without close investigation of the

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[46]U.S. Environmental Protection Agency, "Proposed National Secondary Drinking Water Regulations," Federal Register, Vol. 42, No. 62, March 31, 1977.

[47]Conducted by Deborah Zuckerman, Graduate Research Assistant in Public Health, Denver Research Institute, from available medical data bases, Summer 1984.

[48]Dr. Henry A. Schroeder, Dartmouth College Trace Element Laboratories, reports that people who habitually drink soft water are more likely to die of cardiovascular diseases than people who drink hard water. His work has been corroborated in Canada, England, Sweden and Japan. "Hard Water Preferred for Drinking in Health," [Denver] Rocky Mountain News, October 4, 1986, p. 66.

product, it appears to be a chemical method of creating a scale to inhibit the natural corrosiveness of most water – just what water that is high in salinity does naturally. It also protects against lead, copper, and other constituents undesirable in public drinking water.

Chapter 4, above, contains a lengthy discussion about the damages caused by corrosion vs. scale. While the typical consumer may be more concerned about scale and the dreaded "limestone buildup" in washers or water heaters, the protective aspects of scale in terms of plumbing longevity and appliance life outweigh the problems. Further, reading contemporary users' manuals for water heaters, humidifiers, and some washers gives a consumer instructions on controlling scale buildup beyond that necessary for corrosion protection.

Secondary or Indirect Effects

Only the direct costs, or damages, attributable to salinity have been addressed in this study, as the Bureau of Reclamation specified. It is far beyond the scope of this study to trace and estimate the direction and magnitude of the secondary or indirect effects of salinity, many of which are negative (damages) while others may be positive (benefits) to some regions or economic sectors.

This section will briefly discuss the several types of secondary or indirect effects. However, the discussion will be descriptive rather than analytical. For substantially more complete discussions of indirect effects, the reader is referred to two works of Charles W. Howe.[49]

Salinity effects on agriculture may include such impacts as shifts in crop selection, modification of irrigation practices, reduction in crop yield, reduction in acreage devoted to agriculture, and reduction in values of irrigated land, all of which cause economic damages to farmers in the Lower Basin. Secondary regional damages include reduction in agriculture-related jobs (e.g., food processing, sales by agricultural suppliers to irrigators), possibly some reduction in livestock feeding if feed becomes scarcer and more expensive, reduction in property taxes to local governments reflecting a decline in land values, and a reduction in sales taxes as agribusiness declines.

As Howe points out, a drop in Lower Basin agricultural production may well result in benefits to farmers in other regions of the U.S., if demand stimulates an interregional shift in agricultural production and if the crop can be grown satisfactorily in another region. If so, secondary regional damages to the Lower Basin will be mirrored by secondary regional benefits in the area to which crop production shifts.

Salinity damages to households (consumers) have the primary effect of forcing expenditures for certain goods and services, e.g., water using appliances, water treatment equipment and chemicals, household piping, plumbing labor, radiator repair, and purchases of bottled water. These expenditures come at the expense of other spending that the household would have made, e.g., steaks, wine, vacations, and new televisions. Thus most of the economic effects are shifts (positive or negative) in the sectors affected. The bottled water seller gains and the travel agent loses.

Salinity damages to utilities take the form of forcing larger expenditures on water treatment, on capital investment in system facilities and on system O&M, and perhaps on more expensive water supplies or for blending. Regulatory actions may force spending on brine lines or on reverse osmosis equipment. Administrative and planning costs may rise as well, both among utilities and among government agencies. The primary economic effect will be higher utility rates and taxes (if these added costs can be passed on to consumers and taxpayers) or a compensatory reduction in other types of expenditures, e.g., deferral of salary increases for utility employees, or deferral of increases in local government employment.

[49] Charles W. Howe and Jeffrey T. Young, "Indirect Economic Impacts from Salinity Damages in the Colorado River Basin," Appendix 7 of Andersen and Kleinman, op. cit.; J. Gordon Milliken, Loretta C. Lohman, and Charles W. Howe, Feasibility of Financial Incentives to Reuse Low Quality Water in the Colorado River Basin, Washington, D.C.: OWRT, 1981 (particularly Chapter III and Appendix B).

Similar shifts will occur from added expenses to industry. Costs of added water treatment may be able to be passed along in higher prices, if competitive pressures permit; if not, in reduced profits to shareholders or deferrals of industrial wage increases. None of these secondary effects can be predicted to any degree of accuracy without knowledge of price elasticities and of income and budget constraints.

Secondary effects of salinity beyond the U.S. borders, specifically the damages to Mexico, also are outside the scope of this study. Colorado River salinity has a significant, adverse impact on Mexican agriculture and thus on income, as discussed by Howe, Oyarzabal-Tamargo, and Young.[50] This is both an economic problem to Mexico and a political problem to Mexico and the U.S., resulting in U.S. costs for salinity control planning and construction of salinity control facilities. Such costs will have secondary effects, as well, on taxes or on shifts in government expenditures.

Lag Time in Realizing Benefits of Salinity Control Efforts

As other investigators have pointed out, there is a significant lag time in the physical transport[51] of saline water through the basin. A delay of five to six years may occur in realizing salinity impacts at Imperial Dam from projects in the Upper Basin due to the large storage reservoirs in the basin.

Since the physical lag time of salinity effects is already accounted for in the CRSS projections, no other adjustments are necessary in usring the computer model in calculating future damages or potential benefits from Upper Basin projects.

The lag time may also affect the economic analysis for calculating the relative value of costs and benefits of salinity control projects in the Upper Basin. The expenditures for planning and construction of salinity control projects can take place several months or years before the project effects are measured at Imperial Dam. Accordingly, this lag time effect can be appropriately discounted for any cost/benefit calculation on a specific project basis. For the salinity control program, however, cost-effectiveness as measured in $ per ton removed is the primary economic criterion applied to project analysis. As such, a rigorous benefit/cost analysis as suggested above is not required.

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[50] Howe, Appendix B., ibid. See also Francisco Oyarzabal-Tamargo and Robert A. Young, "The Colorado River Salinity Problem: Direct Economic Damages in Mexico," paper presented at the WesternAgricultural Economics Association, July 1976, Fort Collins. Also, "Economic Impact of Saline Irrigation Water, Mexicali Valley, Mexico," Ph.D. dissertation by Francisco Oyarzabal-Tamargo, Colorado State University, Fort Collins, 1976

[51] Gardner, "Economics and Cost Sharing," pp. 126, 171-75.

chapter 10

DESCRIPTION OF COMPUTER PROGRAM TO ESTIMATE FUTURE SALINITY DAMAGES

Program Features

A computer program, or model, has been designed to provide users with a convenient means of estimating current and future damages from Colorado River salinity. The program calculates four types of damages – agricultural, household (consumer), utility, and industrial – and provides these estimates in summarized form, by year, for the entire Lower Basin. Damages can be displayed and printed, either in tabular or graphical form.

As discussed in chapter 6 of this report, policy-induced damages to water and wastewater utilities have not been made a part of the computer program. This is because such damages are policy-induced rather than physically-induced, probably will vary widely by jurisdiction and locality, and thus cannot easily be computed by a mathematical formula. Such damages need to be separately computed and added to the damages estimated in the computer program Summary.

The program is sufficiently flexible to provide disaggregated data for special purposes. For example, household (consumer), utility, and industrial damages can be provided for each of nine metropolitan areas as well as for the total of these areas. Similarly, agricultural damages can be provided for each of six geographic areas, as well as for the entire Lower Basin. Similar disaggregation can be made to readily generate specific types of damages, e.g., damages to automotive cooling systems, or damages to individual crops (say, avocados). The disaggregation can be selected by the user by a single keystroke.

It is expected that the most common use to be made of the computer program is to test the effects of potential salinity control measures or of changes in river flow on the annual damages from salinity in the Lower Basin. The program readily provides this capability, by allowing the user to temporarily change the TDS levels at various points along the Colorado River, corresponding to the expected results of salinity control measures or changes in river flow. Once the TDS levels are changed, the computer program automatically recalculates all types of salinity damages and displays a summary of them in a form easily compared to the summary of damages at other TDS levels.

For ease of use the program is "menu driven." For example, the program opens by presenting the user with a main menu that displays on the screen the types of input data that can be changed by the user. With a few key strokes the user will be able to load the selected baseline data file and select a major menu item, e.g., "household." Next, the user will be presented with another menu that displays the individual items within the type. Again, by way of example, suppose that "change current data for household items" is selected from the menu. The next display will list such things as "view or change present data for direct/indirect consumer damage." Selection of that sub-menu item will display such things as "water heaters," "faucets," "dishwashers," etc., together with the current values for their mean lifetimes. With one more key stroke the user can select one of these and will be asked for the new value which can be entered at the keyboard.

After the data have been updated and saved, the user can – from another sub-menu – start the "household" portion of the computer program. The program will carry out the analysis as described in the earlier sections of this report and will allow the user to select either a tabular output or a graphics output or both.

In line with the "user friendly" attitude, all input data will be checked by the program for reasonableness. For example, if the user attempts to enter a TDS (mg/L) of less than 0 or greater than 1200, the program will request that the user re-enter the data. This is to prevent, insofar as possible, typographical error on the part of the user.

Although it will be possible to run the program on a large mainframe computer if speed of computation becomes important, at the present time it is not envisioned that such computing power will be necessary. The PC described in the next section should be sufficient to carry out the calculations.

User Instructions

The computer program user requires an IBM-compatible personal computer with at least 256K of main memory, a graphics board (desirable, but not essential), two disc drives which accept 5-1/4" double-sided, double-density floppy discs, and a dot matrix printer. If no graphics board is available, the damage estimates will be provided in tabular form but cannot be printed as bar graphs or line graphs. The user also requires two master discs (both 5-1/4" floppys), one containing the Colorado River Salinity Damage Estimation (CRSDE) program and the other containing the standard CRSDE input data. The user should copy both master discs to avoid possible damage or erasure. It is recommended that several copies of the standard CRSDE input data disc be made, to permit data (e.g., TDS levels at various points along the river) to be changed when testing the effects of changes on annual economic damages, and to permit the changed data to be stored for future use. The computer program can save the damage calculations on the changed input data disc for future review or comparison.

The full user instructions, including illustrations of the program menus and screen displays, are contained in the Handbook to this report. The computer program has four major segments which appear sequentially: I. Agricultural Damages; II. Household Damages; III. Utility Damages; and IV. Industrial Damages. A fifth segment, V. Summary, generates a summary array of each of the four types of damages, plus a total of the four, for each of the years selected.

The user begins with the Agricultural Damages segment and reviews displayed data on TDS/yield relationships for each of nine crops; and data on TDS level, crop value, and crop acreage for those nine crops in each of five agricultural geographic areas. (The program has space for a sixth, Future Agricultural Area, to be added later). The user makes such changes as desired, e.g., changes in TDS level for a future year, and observes the resulting change in estimated damages that are automatically calculated by the program.

It is assumed that the user will wish consistent interrelationships among the various segments of the program. That is, if the user wishes to modify TDS levels in the river for the period 1990-2010, he will enter new TDS data for those years in each of the five agricultural areas. Also, it is expected that he will enter new TDS levels for those same years for the seven metropolitan areas, to generate changes in household, utility and industrial damages. If, as expected, the TDS levels entered in the household segment of the program reflect changes consistent with the changed TDS levels used for agricultural damages (after allowing for blending of Colorado River water with other water supplies used in the metropolitan area), and the same period of years is specified, there will be internal consistency among the four types of damage estimated that appear in segment V. Summary. The program maintains consistency among the population and TDS level data for a given year used in the household, utility, and industrial damages segments, as well as data on discount rate and number of persons per household.

Future Modifications to Program

The design of the computer program permits the user to change most of the input data, and thus update the program to reflect technological or price changes, or the effects of salinity control measures on TDS levels, without need for a major rewriting of the program.

Study resources permitted only limited research during the development of the standard

CRSDE input data relating to various salinity damage functions, such as per capita expenditures and useful life of equipment. The values in the input data disc appear reasonable and reflect the best efforts of the study team in the limited time available, but it is expected that new data will become available in the future that will permit calculation of more accurate damage functions. At some point after experience is gained by users of the program, it is recommended that a centralized effort be made to recalculate damage functions, provide revised CRSDE input data, and modify the computer program wherever it might be made more user-friendly and convenient. To promote consistency and economic efficiency, such an updating effort should be done centrally and the results shared among program users.

As experience is gained in determining the magnitude of policy-induced and regulatory-mandated damages, it may become possible to predict their causation and magnitude. If so, it may be possible to add this as another segment of the computer program.

APPENDIX A

BIBLIOGRAPHY

Books and Government Documents

American Water Works Association, Inc. *Water Quality and Treatment, A Handbook of Public Water Supplies.* Denver: AWWA, 1971.

American Water Works Association Research Foundation. *Water Reuse Highlights*. Denver: AWWA, 1978.

Andersen, Jay C. and Kleinman, Alan P., et al. *Salinity Management Options for the Colorado River.* Logan, Utah: Utah Water Research Laboratory, June 1978.

Arizona Agricultural Statistics Service, *1986 Arizona Agricultural Statistics.* Phoenix: author, July 1987.

Arizona Crop and Livestock Reporting Service. *Arizona Agricultural Statistics.* Phoenix: author, various years.

Arizona Department of Water Resources. *Arizona Water Conservation Requirements: 1980-1990.* Phoenix: author, 1986.

Arizona Department of Water Resources. *Management Plan, First Management Period: 1980-1990; Tucson Active Management Area.* December 1984. *Special Supplement: Chapter IX Augmentation Program.* October 1985.

Arizona Department of Water Resources. *Management Plan, First Management Period: 1980-1990; Phoenix Active Management Area.* December 1984.

Arizona Department of Water Resources. *Groundwater Code Plan of Study: 2nd Groundwater Management Plan.* June 1986.

Arizona Department of Water Resources, Tucson Active Management Area. *A Water Issues Primer for the Tucson Active Management Area.* Tucson: Southern Arizona Water Resources Association, July 1983.

Battelle Columbus Laboratories. *The Effect of Water Quality on Residential Water Heater Life-Cycle Efficiency. Third Annual Report (September 1984 - August 1985).* Chicago: Gas Research Institute, 1985.

Black and Veatch, Consulting Engineers. *Economic Effects of Mineral Content in Municipal Water Supplies.* Washington, D.C.: Office of Saline Water, May 1967.

California Department of Food and Agriculture. *California Agriculture.* Sacramento: author, various years.

California Department of Water Resources, Southern District. *Consumer Costs of Water Quality in Domestic Water Use – Lompoc Area.* Los Angeles: author, June 1978.

California Regional Water Quality Control Board, Los Angeles Region. *Water Quality Control Plan, Santa Clara River Basin (4A).* Appendix with 1978 changes.

California Regional Water Quality Control Board, Los Angeles Region. *Water Quality Control Plan, Los Angeles River Basin (4B).* Appendix with 1978 changes.

California Regional Water Quality Control Board, San Diego Region. *Comprehensive Water Quality Control Plan for San Diego Basin.* July 1975.

California Regional Water Quality Control Board, Santa Ana Region. *Water Quality Control Plan: Santa Ana River Basin (8).* 1984.

California. The Resources Agency. Colorado River Board of California. *Need for Controlling Salinity of the Colorado River.* Los Angeles: author, August 1970.

CH2M Hill, Rubel and Hager, Inc. *Tucson Metropolitan Wastewater Reuse Assessment.* Tucson Water, 1983.

Clark County Department of Comprehensive Planning. *Population Data, 1985.*

Coe, Jack Jacobi. *Water Quality Related Consumer Costs in Domestic Water Use.* Unpublished Doctoral dissertation, University of Southern California, 1982.

Colorado River Basin Salinity Control Forum. *1986 Annual Progress Report: Water Quality Standards for Salinity, Colorado River System.* Author, December 1986.

Culp, Wesner, and Culp. *Water Reuse and Recycling: Vol. 1. Evaluation of Needs and Potential; Vol. 2. Evaluation of Existing Treatment Technology.* Washington, D.C.: Office of Water Research and Technology, April 1979.

Gardner, Richard L. and Robert A. Young. *An Economic Update of the Colorado River Basin Salinity Control Program.* Colorado State University, [nd.]

Gardner, Richard L. *Economics and Cost Sharing of Salinity Control in the Colorado River Basin.* Unpublished Ph.D. dissertation, Colorado State University, Fort Collins, Fall 1983.

Imperial County [CA] Agriculture. 1971-1984.

Kleinman, Alan P. and Brown, F. Bruce. *Colorado River Salinity, Economic Impacts on Agricultural, Municipal, and Industrial Users.* Denver: Bureau of Reclamation, December 1980.

McKee & Wolf. *Water Quality Criteria.* California State Water Resources Control Board: June 1, 1976.

Metcalf and Eddy, Engineers. *The Economic Value of Water Quality.* Washington, D.C.: Office of Saline Water, January 1972.

Miller, Taylor O., Weatherford, Gary D., and Thorson, John E. *The Salty Colorado.* Washington, D.C.: The Conservation Foundation and John Muir Institute, 1986.

Metropolitan Water District of Southern California. *1982 Population and Water Demand Study.* Report No. 946. Los Angeles: December 1982.

Metropolitan Water District. *The Regional Urban Water Management Plan for the Metropolitan Water District of Southern California.* July 1985.

Metropolitan Water District of Southern California. "Review of Report of Orange County Water District," *Water Quality and Consumer Costs.* May 2, 1973.

Metropolitan Water District of Southern California. *Annual Report 1985, 1984, 1983.*

Montgomery, James M. Consulting Engineers. *Water Treatment Design and Principles.* New York: John Wiley & Sons, 1986.

Montgomery-Johnson-Brittain. *Tucson Water Treatment Plant Project; Phase I Preliminary Investigations: Water Quality Objective Report.* Tucson: author, May 1984.

Nevada State Department of Agriculture. *Nevada Agricultural Statistics.* Reno: author, various years.

Novick/Rappaport Associates. *A Survey of Public Opinion Toward Water Issues and Major Water Agencies.* Los Angeles: The Metropolitan Water District, August 30, 1983.

Office of Water Research and Technology, U.S. Department of the Interior and Environmental Research Information Center, U.S. Environmental Protection Agency. *Water Research Capsule Report: Water Factory 21.* Washington, D.C., 1978.

Office of Water Research and Technology. *Industrial Wastewater Reuse: Cost Analysis and Pricing Strategies.* Washington, D.C.: author, April 1981.

Orange County Water District. *Water Quality and Consumer Costs.* author: May 1972.

Orange County Water District. *Evaluation of Membrane Processes andTheir Role in Wastewater Reclamation, Volume II.* Fountain Valley, CA: Office of Water Research and Technology, 1980.

Orange County Water District. *Budget Report: Fiscal Year 1986-87.* Fountain Valley, CA: author, February 1986.

Orange and Los Angeles Counties Water Reuse Study. *Mid-Course Report, 1981; Facilities Plan, 1982.* Los Angeles: Author.

Pima Association of Governments. *Population Handbook,* 1985.

Rand McNally Commercial Atlas. 1985.

Reisner, Marc. *Cadillac Desert: The American West and Its Disappearing Water.* New York: Viking Penguin, Inc., 1986.

Riverside County [CA] Agriculture, 1971-1984.

San Bernardino Valley Municipal Water District. *SBVMWD Rainfall Study First Phase Results.* Author: March 6, 1968.

San Diego, City of. *The City of San Diego Water Utilities Annual Financial Report, Fiscal 1986, 1985, 1984, 1983.*

San Diego County Water Authority. *Water Report—1985.*

SCS Engineers. *The Role of Desalting in Providing High Quality Water for Industrial Use.* Long Beach, CA: October 1972.

C-109929

Tucson Water. *Master Plan and Ten Year Capital Improvement Program: 1986-1996.* November 6, 1985.

U.S. Army Corps of Engineers, Los Angeles District. *Central Arizona Water Control Study: Stage II Report*. March 1981.

U.S. Army Corps of Engineers. *Red River Chloride Control Project, Project Overview and Economic Reanalysis*. Tulsa: author, April 1983.

U.S. Army Corps of Engineers. *Supplemental Data to Arkansas-Red River Basin Design Memorandum No. 25 General Design Phase I—Plan Formulation, Vol. I & II.* Tulsa: author, November, 1980.

U.S. Bureau of Reclamation. *Final Environmental Statement Proposed Central Arizona Project.* Author: September 26, 1972.

U.S. Department of Agriculture. *Final Report, Water Conservation and Resource Development: Colorado River Indian Reservation, Arizona, California*. Washington, D.C.: author, May 1985.

U.S. Department of Commerce. Bureau of the Census. *Census of Population and Housing.* Washington, D.C.: U.S. Government Printing Office, 1980.

U.S. Department of the Interior. Bureau of Reclamation. *Quality of Water: Colorado River Basin, Progress Report No. 12.* Washington, D.C.: U.S. Government Printing Office, January 1985.

U.S. Department of the Interior. Bureau of Reclamation. Colorado River Water Quality Improvement Office. *Status Report, Colorado River Water Quality Improvement Program*. Denver: author, January 1983.

U.S. Department of the Interior. Bureau of Reclamation. *Summary Statistics: Water, Land, and Related Data.* Denver: author, 1975-1985.

U.S. Department of the Interior. Bureau of Reclamation. *Central Arizona Project, Definite Plan Report: Appendix F. Project Lands.* May 1972.

U.S. Department of the Interior. Bureau of Reclamation. Lower Colorado Region, Arizona Projects Office. *Central Arizona Project, Report on the May 1986 Water Supply Study.* Phoenix: author, 1987.

U.S. Department of the Interior, Bureau of Reclamation, Lower Colorado Region. *Stage III Report Addendum: Central Arizona Project. Appendix B: Water Supply and Operations*. Boulder City, NV: author, March 1984.

U.S. Environmental Protection Agency, *The Mineral Quality Problem in the Colorado River Basin: Summary Report.* Washington, D.C.: U.S. Government Printing Office, 1971.

U.S. Environmental Protection Agency. *Quality Criteria for Water.* Prepublication draft.

U.S. Geological Survey. *Water Data Report AZ-82-1, Water Resources Data, Arizona, Water Year 1982.* [Bill Williams River Basin, p. 143.] Author: 1983.

U.S. Water Resources Council. *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies*. Author: March 10, 1983.

University of California, Davis. Department of Land, Air and Water Resources. *Irrigation with Reclaimed Municipal Wastewater: A Guidance Manual.* Sacramento: State Water Resources Control Board, July 1984.

Articles and Pamphlets

Argo, David G. "Water Reuse is a Reality." *U.S. Water News*, September 1986, pp. 16-18.

Arizona Department of Health Services. "Groundwater Quality Update." Summer 1986, Winter 1985, First Quarter 1985, Fall 1985, Fall 1984.

"Battelle Study Determines: Soft Water is Better for Heaters." *U.S. Water News*. November, 1986. p. 10.

Bottled Water Reporter. December/January 1986.

California Department of Water Resources. "Management of the California State Water Project." Bulletin 132-85, September 1985.

Day, Janet. "State Officials Dispute U.S. Study on Lead in Water." *Rocky Mountain News*. November 7, 1986. p. 13.

Gardner, Richard L. and Young, Robert A. "An Economic Evaluation of the Colorado River Salinity Control Program." Department of Agricultural and Natural Resource Economics. Colorado State University. [n.d.]

"'Hard' Water Preferred for Drinking in Health." [Denver] *Rocky Mountain News*. October 4, 1986. p. 66.

"Humidifiers will last longer with bleed off." *Air Conditioning, Heating & Refrigeration News*, September 1, 1986. p. 43.

International Bottled Water Association, "20 Questions About the Bottled Water Industry." no date.

Long Beach Water Department, "How About the WATER in Long Beach?" Pamphlet, 1982.

Long Beach Water Department. "Water Reuse in Long Beach;" "Water Conservation in Long Beach;" and "Water for Long Beach." Department Pamphlets.

Los Angeles Department of Water and Power. "Chemical Analyses of Major Los Angeles Water Supplies, Average for Fiscal Years1985-1986." Form 228. August 1986.

Los Angeles Department of Water and Power, "Questions and Answers About the Quality of Your Drinking Water." Pamphlet. June 1986.

Maas, E.V. "Salt Tolerance of Plants." *Applied Agricultural Research*. Vol. 1, No. 1. 12-26. 1986.

Metropolitan Water District of Southern California. "Reclaiming Water." 1984 Pamphlet.

Metropolitan Water District of Southern California. *Focus*. Number 4, 1986.

Metropolitan Water District of Southern California. *Aqueduct*. Number 3, 1986.

MWD. "How Safe is Safe: Perspectives on Water Purity." Pamphlet, June 1986.

Motorola, Inc. "Update: Current information on the Remedial Investigation/Feasibility Study for the Motorola 52nd Street Facility. June 1986.

Office of Water Research and Technology. "Water Factory 21." *Water Research Capsule Report.* Washington, D.C.: U.S. Government Printing Office, 1978.

Oyarzabal-Tamargo, Francisco, and Young, Robert A. "The Colorado River Salinity Problem: Direct Economic Damages in Mexico." Paper presented at the Western Agricultural Economics Association. Fort Collins: July 1976.

Oyarzabal-Tamargo, Francisco. "Economic Impact of Saline Irrigation Water, Mexicali Valley, Mexico." Ph.D. dissertation. Colorado State University. Fort Collins. 1976.

Patterson, W.L. and Banker, R.F. "Effects of Highly Mineralized Water on Household Plumbing and Appliances." *Journal AWWA.* September 1968. pp. 1060-1069.

Pillsbury, Arthur F. "The Salinity of Rivers." *Scientific American*, July 1981. p. 54.

Pope, Carl. "Should Tap Water Be For Drinking?" *California Magazine*, September 1986. p. 66.

Radiator Reporter & Pricing Guide. Vol. 13. No. 7. July 1985.

Rhoades, J.D. "Salt Problems from Increased Irrigation Efficiency." *Journal of Irrigation and Drainage Engineering.* Vol. 111, No. 3, September 1985. pp. 218-229.

Rhoades, J.D. "Use of Saline Water for Irrigation." Photocopy, [n.d.]

Rhoades, J.D. "Principles and Practices of Salinity Control on Food Production in North America." Photocopy, [n.d.]

Robinson, Jack. "Nitrate Becoming Serious Problem for Water Districts." Riverside [CA] *Press Enterprise.* September 8, 1986. p. B1.

Rowe, Leonard C., and Walker, Monte S. "Effect of Mineral Impurities in Water on the Corrosion of Aluminum and Steel." *Corrosion.* Vol. 17, No. 7 (July 1961), pp. 353t-356t.

"Scale on water heaters has small efficiency impact." article in *Air Conditioning, Heating & Refrigeration News.* August 11, 1986, p. 21.

Sherrard, Joseph H., Moore, Donald R. and Dillaha, Theo A. "Total Dissolved Solids: Determination, Sources, Effects, and Removal." Photocopy, [n.d].

Tihansky, Dennis P. "Damage Assessment of Household Water Quality." *Journal of the Environmental Engineering Division, American Society of Civil Engineers.* August 1974. pp. 905- 917.

Tihansky, Dennis P. "Economic Damages from Residential Use of Mineralized Water Supply." *Water Resources Research.* Vol. 10. No. 2. April 1974. pp. 145-154.

U.S. Environmental Protection Agency. "Proposed National Secondary Drinking Water Regulations." *Federal Register.* Vol. 42. No. 62, March 31, 1977.

Woodard, Gary. "Recharge Only Part of Tucson's Water Picture." *Tucson Citizen.* July 31, 1986.

Miscellaneous

American Water Works Association. "Survey of Operating Data for Water Utilities, 1984."

Arizona Department of Health Services. Total Dissolved Solids Content of Aquifers of the Basin and Range and the C-Aquifer [map]. [nd.]

Arizona Department of Health Services. Total Dissolved Solids Content of Aquifers of the Plateau Uplands [map]. [nd.]

Arizona Department of Water Resources. Computer Printout: "Central Arizona Project Supply, Phoenix, Pinal, and Tucson Active Management Areas, 1990-2025." Phoenix: CAPSIM, 1987.

Central Arizona Project Water Reallocation [table].

Denver Board of Water Commissioners. *Annual Report.* 1985.

Bill Dendy & Associates. Memorandum to J. Andrew Schlange, Manager, Santa Ana Watershed Project Authority. Re: Arlington Basin Desalter, September 8, 1986.

Delaney, Ladin. Lecture notes on energy costs of imported water.

Excerpt of GE Use and Care Pamphlet on Washers, Air-Conditioning and Refrigeration Institute, 1501 Wilson Blvd., Arlington, Virginia 22209

Los Angeles Times, survey, September 1986.

Maricopa Association of Governments Urban Planning Area [map], November 1985.

Maricopa County, AZ. Resident Population Projections Adopted October 22, 1986. Municipal Planning Areas and Districts. 1980-2015 [table].

Maricopa County AZ, special census of 1 October 1985 [table].

Metropolitan Water District of Southern California. Water Distribution System. [map]

MWD. Memorandum from Water Quality Manager. "Preliminary Scope of Work for Water Quality Survey of Bottled Water and Water Dispensing Machines." August 6, 1985.

MWD. Memorandum to Water Quality Manager from Daniel J. Askenaizer. "Report on Bottled Water, December 13, 1985."

Metropolitan Water District of Southern California, computer diskette,: 1974-1985 Crop Revenue Data for the Palo Verde Irrigation District from the County of Riverside Agricultural Commissioner's Office; 1950-84 Crop Acreage Data for the PVID Irrigation District. 1959-84 Annual Consumptive use data for PVID.

Nevada, State of. Office of Community Services. *1986 Statistical Abstract.*

Phoenix. Water and Wastewater Department. *1983-1984 Annual Report.*

San Diego, City of. Water Utilities Department Water Laboratory. "Complete Chemical Analysis Summary." 1983-1985.

San Diego, City of. Water Utilities Department. *Annual Financial Report.* Fiscal Years 1984-1986.

C-109933

Santa Ana Watershed Project Authority. Excerpts from Task Report on Water Quality, "Sensitivity of Quality-Related Consumer Costs to Increases in TDS of Delivered Water." By Leeds, Hill, and Jewett, Inc. 1974.

Sears Roebuck Fall/Winter 1986 Catalogue.

"Southern California Water Supply and Demand Comparison." [nd.] no author.

Sparkletts. Advertising pamphlet for bottled water, August 1985.

Tinney, James Craig. Draft doctoral dissertation. "Trading Quality for Quantity: Salinity Management Strategies for the Tucson Basin." Tucson, AZ: University of Arizona. 1986.

U.S. Bureau of Reclamation, Lower Colorado Region. Report of Water Analysis. 13 May 1986.

Weber, Ernest M. Unpublished lecture notes on salinity and water quality.

APPENDIX B
LIST OF PERSONS INTERVIEWED

Arizona

Personal Interviews

Marybeth Carlile, Executive Director, Southern Arizona Water Users Association, Tucson

Greg Crossman, Civil Engineer, Bureau of Reclamation, AZ Projects Office, Phoenix

V.C. Danos, Program Manager, John R. (Bob) McCain, Program Manager; Robin Stinnett, Assistant to the Director; Arizona Municipal Water Users Association, Phoenix

David Esposito, Pima County Wastewater, Tucson

George Fay, Creative Housing Alternatives, Mesa

Tim Henley, AZ Department of Water Resources, Phoenix

Stephen J. Jenkins, AZ Dept of Water Resources, Economist: Planning and Flood Control, Phoenix

Gail F. Kushner, Environmental Planner, Pima Association of Governments, Tucson

Dr. William B. Lord, Director, Water Resources Research Center, University of Arizona, Tucson

Tom McLean, Planning Administrator, City of Tucson Water Department

Craig D. O'Hare, Water Resources Specialist; Katharine L. Jacobs, Unit Supervisor; Tucson office, AZ Department of Water Resources

Steve Olson, Deputy Director, Tucson Active Management Area, AZ Department of Water Resources

Edwin K. Swanson, AZ Department of Health Services, Office of Emergency Response and Environmental Analysis, Phoenix

Craig Tinney, University of Arizona Ph.D. candidate in Natural Resource Economics, former employee of the AZ Department of Water Resources

Ralph Weeks, V.P., Geology, Sergent, Hauskins, and Beckwith, Phoenix

Gary Woodard, University of Arizona Division of Economics and Business Research, Tucson

Telephone Interviews

Zenas Blevins, Assistant Project Director, USBR Yuma Project

Barry L. Bloyd, State Statistician, Arizona Agricultural Statistics Service, Phoenix

Randy Chandler, Bureau of Reclamation, AZ Projects Office

Tim Henley, AZ Department of Water Resources, Phoenix

Stephen Jenkins, AZ Department of Water Resources, Phoenix

Tom McLean, City of Tucson Water Department, Tucson

Bruce Miles, President, AZ Water Quality Association, Phoenix

Plumbing Inspectors in the Cities of Phoenix, Tempe, Chandler, Mesa, Glendale

Charles Slocum, Assistant Manager, Wellton-Mohawk Irrigation District

Steve Starr, Water Supervisor, City of Chandler

California

Personal Interviews

David Argo, Black and Veatch Engineers, former Asst. General Manager, Orange County Water District

Takashi Asano, Water Reclamation Specialist, CA Office of Water Recycling, Sacramento (interviewed in Denver)

James R. Bennett, Executive Officer, CA Regional Water Quality Control Board, Santa Ana Region, Riverside

Neil Cline, Manager, Orange County Water District

Dennis Dasker, Senior Water Resource Control Engineer, CA Regional Water Quality Control Board, Los Angeles Region

Ladin Delaney, CA Water Quality Control Board, San Diego Region, San Diego

William Dunivin, Operations Mgr.; James A. Van Haun, Intergovernmental Relations Specialist; Orange County Water District

Louis Fletcher, Mgr., San Bernardino Municipal Water District

Dr. Ahmad A. Hassan, Chief, Resources Inventory Branch, CA Dept of Water Resources, Southern District, Los Angeles

Le Val Lund, Engineer; Olsen J. Rogers, Chief Chemist; Los Angeles Department of Water & Power

Frank Maitski, San Diego Wastewater Resources Recovery and Control

William T. McWilliams, Bureau Engineer, Bureau of Water Supply and Distribution, Long Beach Water Department

Lawrence R. Michaels, General Manager, San Diego Water Authority

Jim Miller, Riverside County Building Department

J. Andrew Schlange, Mgr. and James W. Anderson, attorney, Santa Ana Watershed Project Authority, Riverside

Will Sniffen, Water Production Division, San Diego Water Department

Dennis Underwood, Executive Director, Colorado River Board of California, Los Angeles

Ernie Weber, Colorado River Board of California, Los Angeles

Metropolitan Water District of Southern California: Jan Paul Matusak, Engineer, Resources Division; Dr. Wiley Horne, Director of Planning; Rich Atwater, Director of Resources; Jim Daber, Associate Engineer, Resources Division; Dan Askenaizer, Administrative Assistant, Water Quality Division; Jay Malinowski, Assistant Director, Public Affairs; Dora Tom Lee, Librarian

Telephone Interviews

Doyle Boen, retired general manager, Eastern Municipal Water District

Dr. Jack Coe, engineer, La Puente

Don Cox, farmer, Imperial Irrigation District

Jerry Davidson, General Manager, Palo Verde Irrigation District

Carolyn Fahnestock, Executive Director, Pacific Water Quality Association, Huntington Beach

Claude Finnell, Imperial County Commissioner of Agriculture

Dana Fisher, farmer, Palo Verde Irrigation District

Steve Hinderer, public relations, Los Angeles Department of Water and Power

Plumbing Inspectors in Riverside, San Diego, Palm Desert, Los Angeles, Glendale, Pasadena, etc.

Dr. James Rhoades, U.S. Salinity Laboratory, Riverside

Chuck Shreves, General Manager, Imperial Irrigation District

Ernie Weber, Colorado River Board of California

George Wheeler, Water Manager, Imperial Irrigation District

Colorado

Personal Interview

George L. Craft, Resources Engineer, American Water Works Association, Denver

Telephone Interviews

Michael Clinton, USBR retired

David H. Merritt, Colorado River Water Conservation District, Glenwood Springs

Nevada

Personal Interviews

George S. Blake, Water Resources Engineer, Colorado River Commission of Nevada, Las Vegas

Nate Cooper, Research Associate, Desert Research Institute, Water Resources Center, Las Vegas

Robert W. Johnson, Tim Ulrich, Economic Resources Branch, USBR, LC Region, Boulder City

Phillip W. Kobett, Supervising Design Engineer, Nevada Power Company, Las Vegas

H. Grant Laughter, Plant Engineer, Clark Station, Nevada Power Company, Las Vegas

James L. Ley, Assistant Director, Clark County Dept. of Comprehensive Planning, Las Vegas

Thomas J. McCaffrey, Sanitary Engineer, Dept. of Public Services, City of Las Vegas

Dr. Douglas A. Selby, Manager, Technical Services Division, Clark County Sanitation District, Las Vegas

Robert W. Sullivan, Deputy General Manager, Water Systems, Las Vegas Valley Water District, Las Vegas

Telephone Interviews

C.H. Barr, Plant Manager, Stauffer Chemical Co., Henderson

Rolfe B. Chase Jr., Plant Manager, Kerr McGee Chemical Corp., Henderson

Frank Louden, Nevada Power Company, Las Vegas

David P. Odell, Plant Engineer, Sunrise Plant, Nevada Power Company, Las Vegas

Arthur Reber, Plant Manager, Genstar Lime Co., Henderson

Dr. Mark Small, Environmental Coordinator, Titanium Metals Corp. of America, Henderson

Glen Taylor, Basic Management, Inc., Henderson

Alan F. Walter, Chief Engineer, Las Vegas Valley Water District, Las Vegas

C-109938

General Telephone Interviews

Layne Adams, Copper Development Agency, Glendale, CA

Appliance Consumer Action Panel, Chicago

Association of Metropolitan Sewerage Agencies, Washington, D.C.

Automobile Service Council, Phoenix

Construction Industry Research Board, Glendale, CA

Bill Deal, Exec. V.P., International Bottled Water Institute, Washington, DC

Gas Research Institute, Chicago

Tom Higham, International Association of Plumbing and Mechanical Officials, Los Angeles

Jess Hill, Los Angeles Association of Plumbing-Heating-Cooling Contractors

International Conference of Building Officials, Los Angeles

National Association of Plumbing-Heating-Cooling ContractorsWashington, D.C.

National Housewares Manufacturers Association, Chicago

Dorie Nelson, Association of Home Appliance Manufacturers, Chicago

Jane O'Brien, Beverage Marketing Association, New York

Douglas Oberhamer, Water Quality Association and Research Council, Lisle, Illinois

Bob Payne, Exec. V.P., Plumbing Piping Industry Council, Los Angeles

Plumbing Inspectors for City and County Governments:
Las Vegas Building Department, City of Los Angeles; County of Los Angeles; Maricopa County, AZ; City of Mesa, AZ; City of Glendale, AZ; City of Tucson, AZ; City of Tempe, AZ; City of Phoenix, AZ

Staff Librarians, American Water Works Foundation, Denver

Water Pollution Control Federation, Alexandria, VA

Don Waters, Corrosion Engineers, San Diego

C-109939